Estimating Bus Delay at Signalized Intersections from Archived AVL/APC Data

by

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The travel times of public transit systems that operate on mixed use right-of-ways are often dictated by the delays experienced at signalized intersections. When these delays become large and/or highly variable, transit quality degrades and agency operating costs increase. A number of transit priority measures can be applied, including transit signal priority or queue jump lanes. However, it is necessary that a process of prioritizing intersections for priority treatment be conducted so as to ensure the greatest return on investment is achieved.

This thesis proposes and demonstrates a methodology to determine the distribution of stopped delays experienced by transit vehicles at signalized intersections using archived AVL (automated vehicle location) and APC (automated passenger counting) data. This methodology is calibrated and validated using queue length and bus unscheduled stopped delay data measured at a field site. Results show the proposed methodology is of sufficient accuracy to be used in practice for prioritizing signalized intersections for priority treatment. On the condition that a sample of the transit vehicle fleet is equipped with an AVL/APC system, the proposed methodology can be automatically implemented using the archived AVL/APC data and therefore avoid the need to conduct dedicated data collection surveys.

The proposed methodology can provide estimates of (1) the maximum extent of the queue; and (2) measures of the distribution of stopped delays experienced by transit vehicles (e.g. mean, standard deviation, 90th percentile, etc.) caused by the downstream traffic signal. These measures can be produced separately for different analysis periods (e.g. different times of the day; days of the week; and time of the year) and can be compiled separately for different transit routes. These outputs can then be used to identify and prioritize signalized intersections as candidates for transit signal priority measures.

The proposed method is suitable for application to most transit AVL/APC databases and is demonstrated using data from Grand River Transit, the public transit service provider in the Region of Waterloo, Ontario Canada.

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a	=	Y-axis intercept of the boundary line function
A	=	Area defined by the delay envelope boundary line
A_c	=	Start time of bus stop event
$A_{i,j}$	=	Area defined by the delay candidate delay envelope boundary line $C_{i,j}$
b	=	Slope of the boundary line function
C	=	Capacity of intersection approach (veh/h)
$C_{i,j}$	=	Candidate delay envelope boundary line
d	=	Stop delay which occurs when a vehicle stops at the stop line
d_{max}	=	Maximum stopped delay which occurs when a vehicle stops at the stop line at the end of the green interval (seconds) which is also Y-axis coordinate of horizontal pivot line
D_c	=	End time of bus stop event
$D_{i,j}$	=	Density of stopped delay observations
$\Delta D_{i,j}$	=	Change in density between each pair of consecutive candidate boundary lines $C_{i,j}$ and $C_{i,j+1}$
g_e	=	Duration of effective green interval (seconds)
I	=	Index value ($0 < I \leq 100$) in which a higher value indicated indicates higher priority
k	=	Number of "milepost" on line $y = d_{max}$ or X-axis
l	=	The distance between every two horizontally consecutive mileposts (this is also referring to bin size
m	=	Mean stopped delay (seconds)
m_j	=	"Milepost" i on the X-axis from $(l, 0)$ to $(X_P, 0), j = 1,2,3 \ldots k$
m_{max}	=	Maximum value of m across all intersection approaches
m_{min}	=	Minimum value of m across all intersection approaches
M_d	=	Normalized mean stopped delay, which is equal to $(m - m_{min})/(m_{max} - m_{min})$
n	=	90th percentile of mean stopped delay (seconds)
n_d	=	Number of observations of subset of stopped delay for calculating d_{max}
n_i	=	"Milepost" i on line $y = d_{max}$ from $(0, d_{max})$ to $(X_P - l, d_{max}), i = 1,2,3 \ldots k$
n_{max}	=	Maximum value of n across all intersection approaches
n_{min}	=	Minimum value of n across all intersection approaches
N_d	=	Normalized 90th percentile of stopped delay, which is equal to $(n -$

n_{min})/($nmax$ $-$ n_{max})

$N_{i,j}$	=	Number of stopped delay observations located below and to the left of the boundary line $C_{i,j}$
N_{min}	=	A constant reflecting the minimum number of observations to be considered for computing d_{max}.
N	=	Total number of stopped delay observations on the route segment
N_s	=	Cumulative number of stopped delay observations as a function of location of unscheduled stopped delay
o	=	Distance (m) between n_1 and n_i
p	=	Proportion of trips having to stop ($0 \leq p \leq 100\%$)
p_{max}	=	Maximum value of p across all intersection approaches
p_{min}	=	Minimum value of p across all intersection approaches
P	=	Normalized proportion of trips having to stop, which is equal to $(p - p_{min})/(p_{max} - p_{min})$
P_{delay}	=	User define percentile (0.0 < P_{delay} < 1.0) of the sub-set of stopped delay used to determine d_{max}
P_{obs}	=	User defined percent (0.0 < P_{obs} < 1.0) used to determine the sub-set of stopped delay data for finding d_{max}
r	=	Effective red time (seconds)
x	=	Unscheduled stop location relative to stopline at downstream intersection (m)
X	=	Volume-to-capacity ration; ($X = \frac{\lambda}{c}$)
X_0	=	Number of passenger car units (PCU) in the queue
X_1	=	AVL/APC bus unscheduled stop location distance
X_3	=	AVL/APC stopped delay
X_N	=	X-axis coordinate of the most upstream observed stopped delay (m)
X_P	=	X-axis coordinate of vertical pivot line
X_{max}	=	Maximum distance upstream of stop-line that queue is expected to reach (m)
Y_0	=	predicted queue length
Y_1	=	Predicted bus unscheduled stop location distance
Y_3	=	Predicted total delay
λ	=	Volume of intersection approach (veh/h)

Terminology

Mid-block transit stop: A scheduled transit stop location which is more than 50m upstream from the downstream signalized intersection.

Near-side transit stop: A scheduled transit stop location which is within 50m of the downstream signalized intersection.

Route segment: Road section between two consecutive signalized intersections along a given route and direction.

Scheduled Stop: A scheduled stop is a transit vehicle stop event that occurs at a location which is part of the scheduled stop locations. Scheduled stop locations include terminals and designated transit stops.

Transit vehicle stop event: A transit vehicle stop event is a data record within the AVL/APC database. A stop event record is generated each time the transit vehicle speed is close to zero. A stop vent record is generated at the time the transit vehicle comes to a stop and when it starts to move again.

Unscheduled stop: An unscheduled stop is a transit vehicle stop event that occurs at a location which is not part of the scheduled stop locations. Examples of unscheduled stops are those that occur at signalized intersections, stop or yield controlled intersections, at-grade rail crossing, congestion, etc.

Unscheduled stop delay: This is the duration of each unscheduled stop event as determined by the difference between the time the transit vehicle comes to a stop and then begins to move again.

Unscheduled stop location: The location of an unscheduled stop measured from the stopline of the downstream signalized intersection.

Chapter 1: Introduction

1.1 Background

Intersections typically constitute the capacity bottlenecks within most urban arterial road networks. Consequently, the majority of delays are experienced at intersections. For transit services that operate within mixed use right of ways, intersection delays can constitute a large portion of the route cycle time. For these conditions, reducing the intersection delays to transit vehicles improves quality of service for transit users and saves transit agency operating costs by reducing route travel times.

There exist a number of treatments by which intersection delays to transit vehicles can be reduced including:

1. Transit signal priority (such as green extension and/or early green)
2. Specialized transit vehicle only signal phases
3. Queue jump lane for transit vehicle

Each of these treatments has unique operational characteristics and no one treatment is suitable for all conditions. However, a common challenge that agencies face when considering these treatments is obtaining reliable data that quantifies the delays that transit vehicles experience under existing conditions.

Traditionally, data to quantify transit vehicle delays at intersections has been collected manually through dedicated survey in which surveyors equipped with stop watches and/or GPS data loggers measure intersection delays for a sample of transit vehicles. This approach is costly and therefore typically surveys are conducted for a limited number of intersections, over short time periods (e.g. AM and PM peak hours of a single day) and capture only a relatively small sample of the transit vehicles. The resulting sample of field observations is usually small, limiting the transit agency's ability to accurately identify the magnitude and variation (e.g. time of day, day or week, and seasonal variations) of intersection delays over the entire network. These limitations then also limit the transit agency's ability to reliably identify the intersections (and approaches) that cause the largest delays to transit vehicles and to prioritize those intersections for priority treatment on the basis of both the delays that transit vehicle experience at these locations and the potential to reduce these delays.

However, the increasingly widespread adoption by transit agencies of AVL (automated vehicle location)/APC (automated passenger counting) technologies provides an opportunity to obtain a very large set of data covering all equipped transit vehicles over all intersections and over all service hours.

AVL and APC systems are introduced to improve safety, efficiency and quality of service in public transportation. Originally, AVL was designed for real time monitoring (e.g. assisting computer aided dispatching system) and offline analysis while APC was dedicated for archived data only focusing on offline analysis. More recently, transit agencies have begun to deploy AVL and APC as integrated systems (e.g. Tri-Met, GRT) as deploying them as integrated systems results in lower installation and operating costs than when the two systems are deployed as separate, independent systems. A typical structure of AVL/APC system on a bus is depicted in Figure 1.

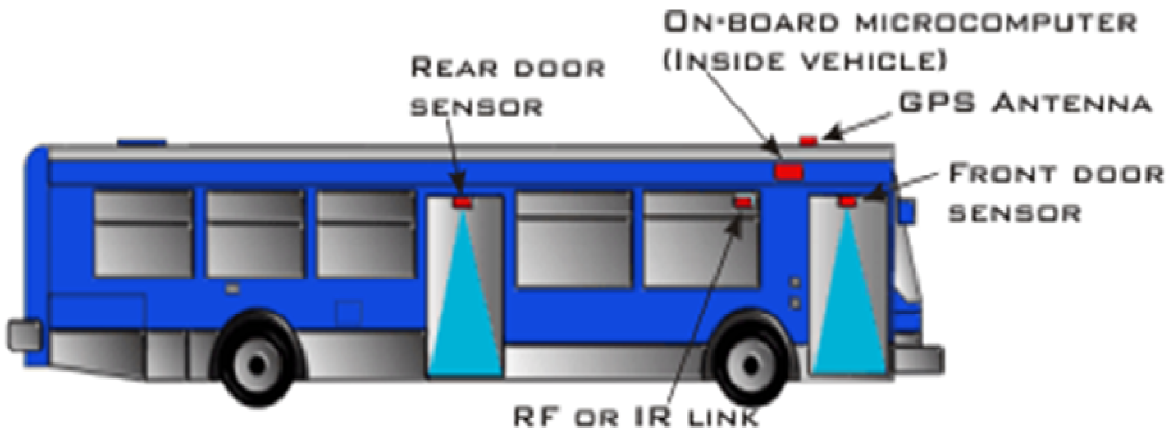


Figure 1. Typical structure of a bus equipped with AVL/APC (Source: INFODEV)

Data recorded by the AVL/APC system are typically archived into the transit agency's database on a daily basis. Typically, these data are stored as trip-level records and as stop-level records. Trip-level records contain information pertaining to each individual transit trip such as a unique record ID number, observation date, route name (defined by transit agency), direction (defined by transit agency), scheduled start time, scheduled end time, actual start time, actual end time, trip type (e.g. service trip, dead run, etc.) and so on. Stop-level records contain information pertaining to specific pre-defined events. Events are defined by criteria such as transit vehicle speed, position relative to a schedule transit stop, status of the doors (e.g. open or closed), etc. For example, a stop-event record is generated each time a transit vehicle decelerates to zero speed or accelerates from zero speed. If the position at which the transit vehicle has come to a stop (i.e. zero speed) is at the location of a transit stop, then this event is designated as a "scheduled stop". Conversely, if the location is not at a transit stop, then this event is designated as an "unscheduled stop".

Every event record consists of the following data: unique record ID, observation date, trip ID, stop type (defined by transit agency), scheduled arrival or departure time (this is only applicable for scheduled stops), actual arrival or departure time, passenger activity information (boarding, alighting, load), location information (e.g. odometer, GPS data) and so on. It can be seen that these AVL/APC data can be used to generate easy-to-access and valuable information to assist transit agencies to monitor the quality of delivered service and to assist in service planning.

1.2 Motivation

A great deal of research has been reported in the literature addressing the use of AVL and APC data for a variety of purposes. Utilization of AVL/APC data involves applications using timepoint records (e.g. schedule adherence monitoring), transit stop records (e.g. passenger crowding analysis), stop records (e.g. mapping route) and so on (Furth et al. 2006). Mandelzys (2010) proposed a method to evaluate transit schedule adherence and identify causes of poor performance using timepoint records. Liao et al. (2010) proposed a data processing framework to analyze transit performance on stop and route levels based on timepoint records. Golani (2007) proposed visualization of transit performance measures including schedule deviation and passenger counts in a GIS (geographical information system) environment using timepoint and transit stop records. However, there appears to have been very little work done to leverage the databases produced by these AVL/APC systems to quantify the delays caused to transit vehicles by signalized intersections. Given the large effort (and cost) associated with collecting transit vehicle delay data at signalized intersections using other methods, there appears to be substantial benefit to extracting these estimates of delay from archived AVL/APC data.

1.3 Problem Definition

Delays for public transit vehicles are divided into two categories:

Case 1: The transit vehicle joins a stationary queue.

Case 2: The transit vehicle slows down to join the tail of a queue of slowly moving vehicles (but the transit vehicle does not come to a stop).

Naturally, a transit vehicle may experience multiple Case 1 and/or Case 2 events when traversing a given intersection approach. The two cases identified above are illustrated in Figure 2. Typically, AVL/APC systems are configured to provide data in one of three ways:

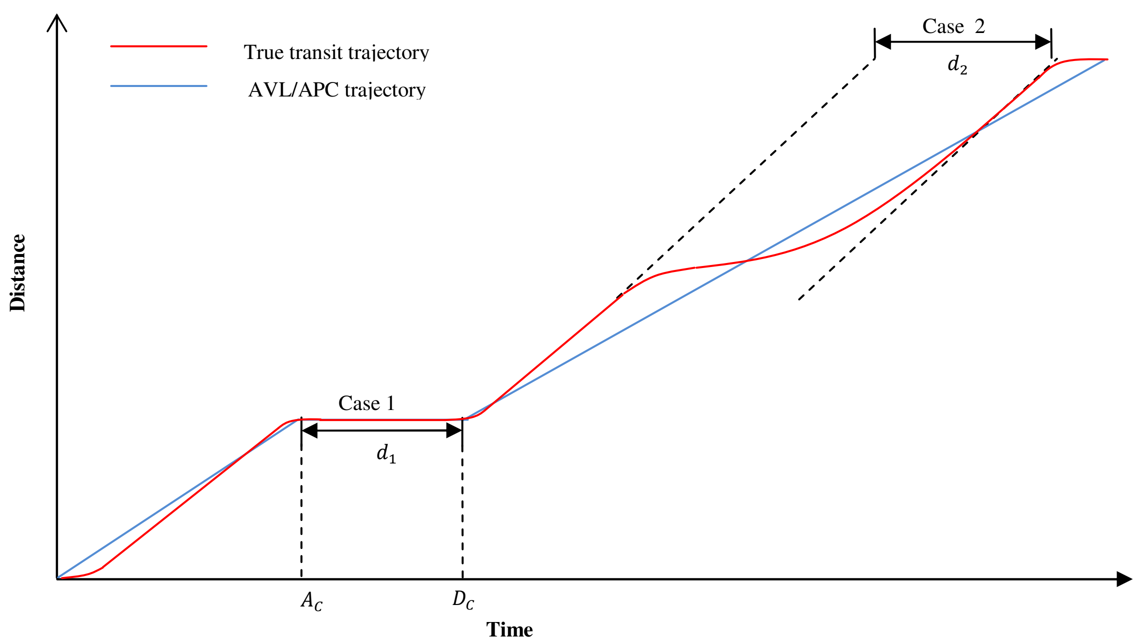


Figure 2. True transit vehicle trajectory and AVL/APC trajectory

1. Fixed Frequency: The position of the transit vehicle is recorded at a fixed time frequency of say 30 seconds.
2. Event Based: Data are recorded when pre-defined events occur such as the doors open or close; the transit vehicle decelerates to stop (zero speed) or accelerates from a stop (zero

speed); or the transit vehicle arrives at or departs from a transit stop. For each event, the position, time and event type are recorded in the database.

3. Combined Fixed Frequency and Event Based: Data are recorded when pre-defined events occur but also at fixed time frequencies.

If the AVL/APC system is configured to be either "Event Based" or "Combined Event and Fixed Frequency Based", then the start time (A_c) and end time (D_c) associated with each Case 1 delay (i.e. stopped delay) are directly recorded and the stopped delay d_1 can be calculated by $D_c - A_c$. In contrast, Case 2 delays (i.e. acceleration and deceleration delays when the transit vehicle does not stop) cannot be directly quantified.

If the AVL/APC system is configured as "Fixed Frequency" then the ability to identify d_1 or d_2 is a function of the duration of d_1 and d_2 relative to the frequency at which transit vehicle positions are recorded. The method proposed in this thesis assumes that the AVL/APC system provides event data. Case 1 delays are represented by "unscheduled stop" in this event-driven system.

It is expected that total delay to transit vehicles is likely dominated by stopped delay (Case 1) rather than Case 2 delays. However, not all Case 1 delays belong to signal-caused delay. There are multiple reasons that can cause Case 1 delays as shown in Figure 3.

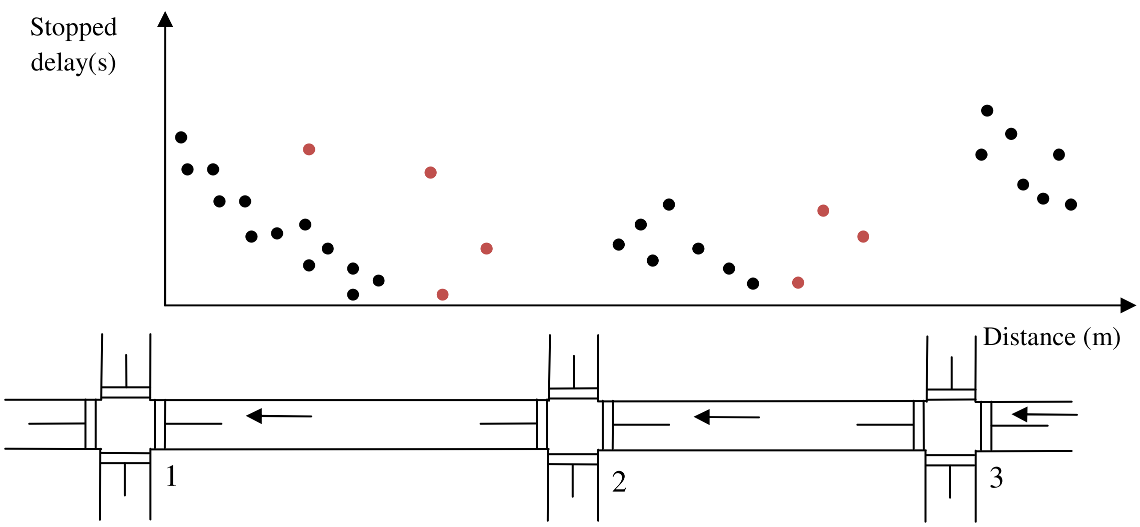


Figure 3. Unscheduled stop delays caused by multiple sources

Figure 3 depicts a section of roadway in which there exists three signalized intersections. Vehicles may experience unscheduled stop delays caused by the traffic control devices (e.g. intersections 1, 2, and 3) or by other factors such as vehicles attempting to make parking manoeuvres, vehicles stopped in the travel lane (e.g. service vehicles), incidents, etc. These delays are not caused by the signalized intersections and therefore should not be considered when estimating the delays to transit vehicles caused by the signalized intersections (In Figure 3 these are depicted as the red points).

Furthermore, queues forming from signalized intersections may extend upstream and interact with queues caused by upstream intersections (e.g. the queues formed at intersection 1 may spill back upstream of intersection 2). When this occurs, there are additional challenges for determining the delays caused to transit vehicles by the signalized intersection at 1.

We begin by assuming that the transit route is divided by direction and then into *segments*, where each segment consists of the portion of the directional route between two consecutive signalized intersections. Unscheduled stops made by transit vehicles on each route segment can be categorized into three types as follows:

Category 0: Unscheduled stop caused by a downstream traffic signal control.

Category 1: Unscheduled stop caused by random factors such as congestion, emergency vehicle, parking manoeuvres, stalled vehicle, bus breakdown, incident, etc.

Category 2: Unscheduled stop caused by other geometric (e.g. at-grade rail crossings) or traffic control (e.g. unsignalized intersections with stop or yield control) features.

Based on the definitions of these categories, only **Category 0** stops can be used to estimate transit vehicle delays caused by signalized intersections. However, within the archived AVL/APC database all unscheduled stops are stored as a single type of record. Consequently, in order to properly estimate transit vehicle delays caused by traffic signals it is necessary to develop an appropriate methodology to:

1. Determine which set of unscheduled stop records can be identified as Category 0, and
2. Address the situation when queues resulting from more than one geometric feature interact.

1.4 Goals and Objectives

This thesis seeks to answer the following five research questions:

1. How can AVL/APC databases be used to automatically quantify the delay that transit vehicles experience as a result of signalized intersections?
2. How accurate/reliable are these estimates?
3. How variable are transit vehicle delays at signalized intersections?
4. What measures can be used to prioritize intersections for transit priority treatments?
5. What intersections within Waterloo Region cause the largest delays to transit vehicle operations?

To answer these research questions, this thesis has four objectives:

1. Develop a model for estimating transit vehicle delays caused by signalized intersections.
2. Validate this model.
3. Demonstrate the model using AVL/APC data from Grand River Transit in Waterloo Region.
4. Conduct a case study evaluation of transit vehicle delays caused by signalized intersections on routes within Waterloo Region.

1.5 Thesis Outline

There are 6 chapters included in this thesis. Chapter 2 gives a literature review on previous work on how to determine transit vehicle delays at intersections so as to determine implementation of transit priority treatments. Chapter 3 describes the proposed methodology. Chapter 4 presents the validation of the proposed methodology using data from Grand River Transit in Waterloo Region. Chapter 5 presents a case study of the application of the model to Grand River Transit in Waterloo Region. Chapter 6 provides conclusions and recommendations.

Chapter 2: Literature Review

This chapter reviews previous work on determining traffic delay measurements (e.g. mean, variation, etc.) at signalized intersections and how these measurements play a role in the implementation of transit signal priority (TSP) strategies.

2.1 Traffic Delay at Signal Intersections

In the Highway capacity Manual (HCM, 2000), delay is defined as the difference between the travel time actually experienced and the reference travel time that would result during ideal conditions (i.e. free flow condition). For signal control delay, delays are caused by the signal operations and the geometric and traffic conditions present (Click, 2003).

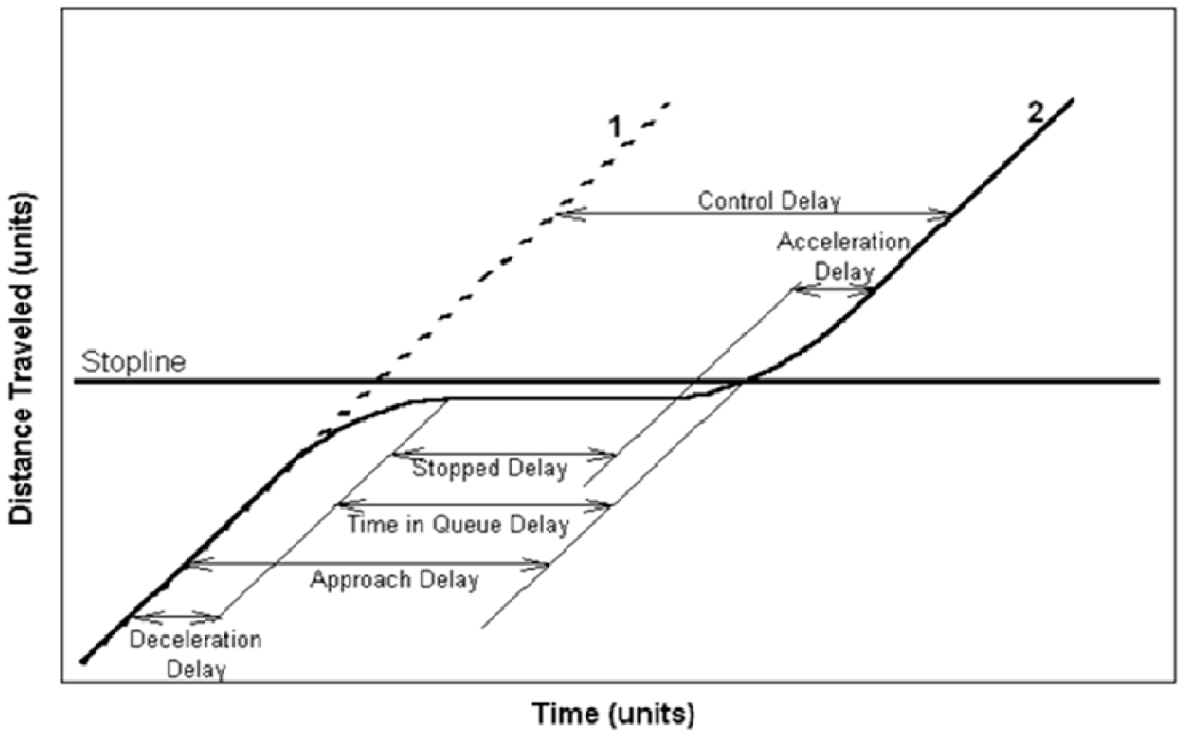


Figure 4. Signal control delay definitions (Source: Click, 2003)

The components of signal control delay are as shown in Figure 4. The line marked 1 is the trajectory of the transit vehicle if no delay is experienced at the intersection. The line marked 2 is the actual trajectory of the transit vehicle. The total delay is the composed deceleration delay, stopped delay, and acceleration delay. Approach delay is the total delay experienced upstream of the stop line.

There has been a great deal of research associated with the development of methods for estimating all or some of these components of signal control delay. Typically, these methods are categorized into the following three streams (Abdy 2010):

1. Field measurements
2. Microscopic simulation
3. Analytical expressions for quantifying delay

The following sections describe previous research in each of these categories separately.

2.1.1 Field Measurement Method

The direct measurement of delays in the field is attractive as the results are subject only to measurement errors. However, traditional field measurement techniques, in which human observers are used, are resource intensive and measuring delays is not trivial. The measurement errors associated with this method are difficult to control and are largely dependent on the skills and attentiveness of the observers.

More recently, advanced traffic sensor technologies have been developed and applied to collect field data. Examples include the use of video image processing, tracking the travel times of individual vehicles using automated number (license) plate recognition (ANPR) systems or other automatic vehicle identification (AVI) technologies, etc. However, these technologies are relatively expensive and are typically only used to collect data for specific studies (having limited spatial and/or temporal scopes) or are implemented as part of another system (e.g. tolling).

In a study done by Mazloumi et al. (2010) surveyors were used to track the path of some individual vehicles. Plate number and passing times of the vehicles which passed predefined points were recorded, however; as it is hard for surveyors to observe and report the plate number of all vehicle when traffic volumes are high, they only considered vehicles with a specific colour (e.g. white). Then the delay is calculated by comparing the travel times observed to those associated with free-flow conditions.

Mousa (2002) devised a method using a series of screen lines at an intersection to measure both the acceleration/deceleration delay and the stopped delay. Every screen line was assigned to one person who was responsible for video-taping randomly selected vehicles. Later on, these recorded tapes were replayed to obtain crossing times of the traced vehicle at every screen line in order to plot vehicle trajectories and estimate delay as shown in Figure 5. This study found that using the method is very time consuming due to the large amount of data that needs to be processed.

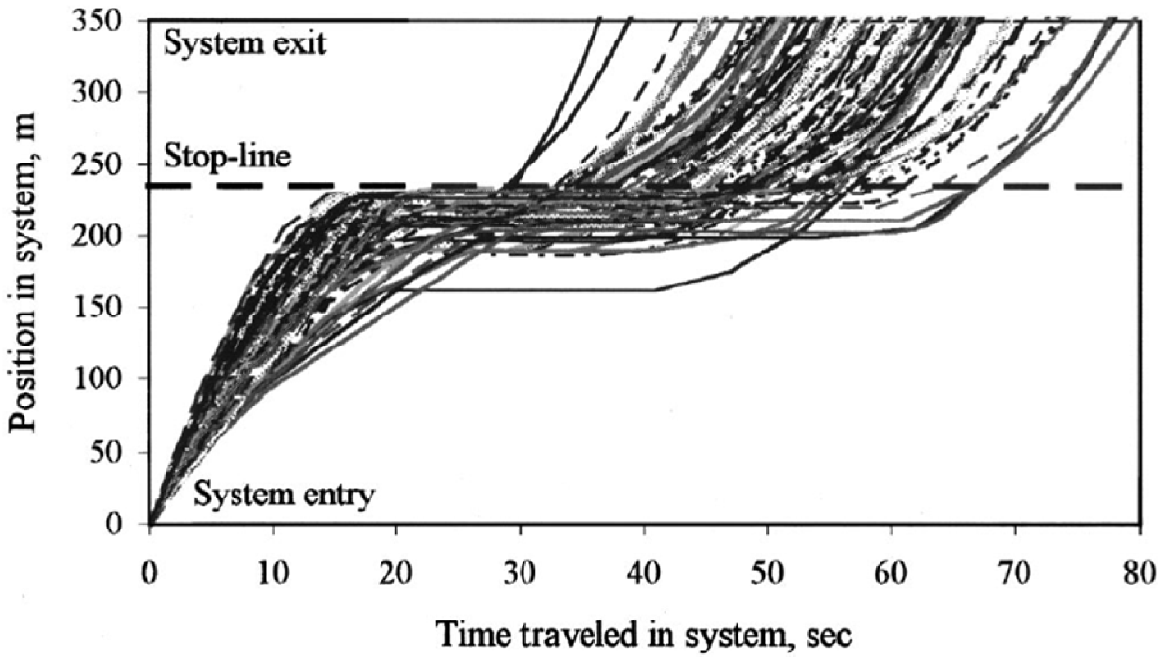


Figure 5. Trajectories of stopped vehicles at signalized intersection (Source: Mousa 2002)

Ko et al. (2008) developed a form of delay measurement with a degree of automation by using GPS data from GPS equipped probe vehicles. Since GPS equipment could capture high-resolution speed profile of vehicles as shown in Figure 6, it allows the observer to calculate deceleration, stopped and acceleration delays relatively precisely.

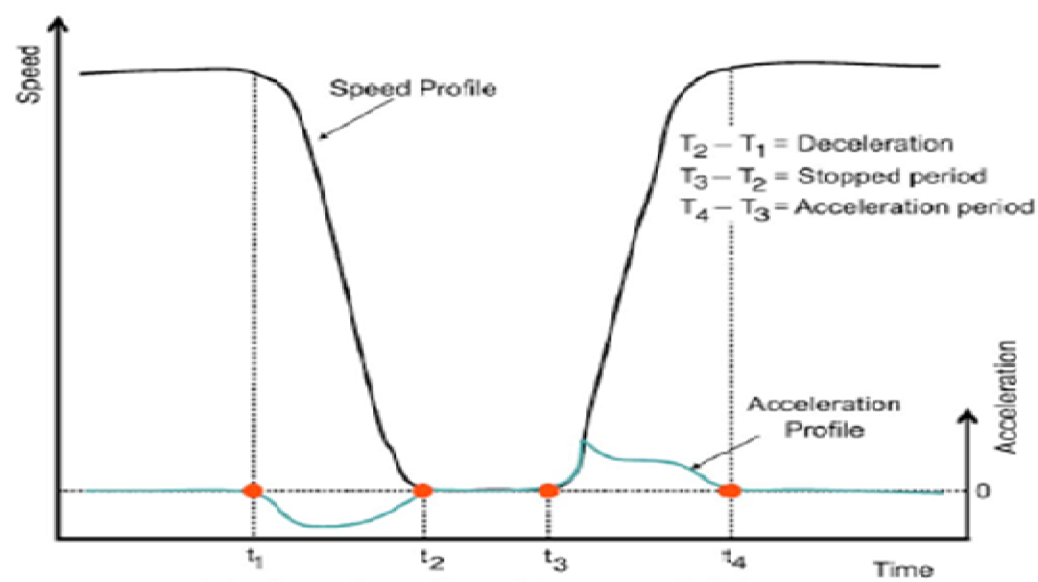


Figure 6. Speed profile captured by GPS (Source: Ko et al. 2008)

Recently, AVL/APC systems have become a prominent method for data collection by transit agencies. The ability to track all AVL/APC equipped vehicles in a fleet and record a variety of information for each vehicle allows for numerous applications of the data. Since one important hardware component of AVL/APC system is GPS equipment, AVL/APC has the ability to record speed and time relationship as shown in Figure 6. However, this method requires either that the AVL/APC systems are modified to record and archive position data at a fixed (high) frequency, or dedicated GPS equipment must be used for the purpose of delay studies. Both of these options entail additional costs for the transit agency and defeat the objective of estimating transit vehicle delays using existing AVL/APC infrastructure.

AVL/APC systems which store high frequency location and speed data are rarely found among agencies (Furth et al. 2009 23). Instead, most transit AVL/APC systems (including the one used by Grand River Transit (GRT) the transit service provider in the Region of Waterloo) are configured as event-driven systems. Table 1 shows an example of event-driven AVL/APC data types provided by the GRT system.

Table 1. GRT AVL/APC event type description (Source: Region of Waterloo)

Stop type	Description
0	planned stop
2	stop with doors
3	stop without doors
4	drive through
5	stop without nominal time
6	drive through without nominal time
Note : Type 0: Bus stop at planned stop (timepoint) with nominal time; Type 2: Bus stop at someplace else (neither planned stop nor on-call stop stop) with doors switch; Type 3: Bus stop at someplace else (neither planned stop nor on-call stop stop) without doors switch Type 4: Bus drives through planned stop with nominal time; Type 5: Bus stop at on-call stop without nominal time; Type 6: Bus drives through on-call stop without nominal time.	

A hypothetical scenario, as shown in Figure 7, is used to explain how GRT AVL/APC system archives these types of event data. The x-axis in Figure 7 depicts time. The left-hand y-axis depicts distance along the route and the right-hand y-axis is speed of the transit vehicle. The heavy solid line depicts the position of the transit vehicle over time (i.e. the trajectory). The light solid line depicts the speed of the transit vehicle as a function of time. The horizontal dashed lines indicate the location of scheduled transit stops. The light green lines represent scheduled transit stops at which the transit vehicle must stop even when no passengers on the transit vehicle wish to exit at the stop and no passengers are waiting at the stop to board the transit vehicle. The orange lines represent transit stops at which the transit vehicle only stops when passengers on board the transit vehicle indicate that they want to exit at the stop or passengers are waiting at the stop to board the transit vehicle (these are termed on-call stops).

There are two conditions that trigger the generation of a stop record within the GRT AVL/APC system:

1. The speed of the transit vehicle is nearly zero (i.e. the transit vehicle stops), or
2. The transit vehicle passes a transit stop.

Some additional conditions are used to define the six stop record types listed in Table 1. For example, if the transit vehicle speed is lower than the threshold value (i.e. trigger condition 1 is met), the transit vehicle is not at a transit stop location, and the bus doors are not opened, then the stop event is classified as type 3. However, if the transit vehicle speed is lower than the threshold value (i.e. trigger condition 1 is met), the transit is not at a transit stop location, and the transit vehicle doors are opened, then the stop event is classified as type 2.

Based on these definitions, Type 3 stop records should be used for estimating transit vehicle stop delays that result from traffic signals.

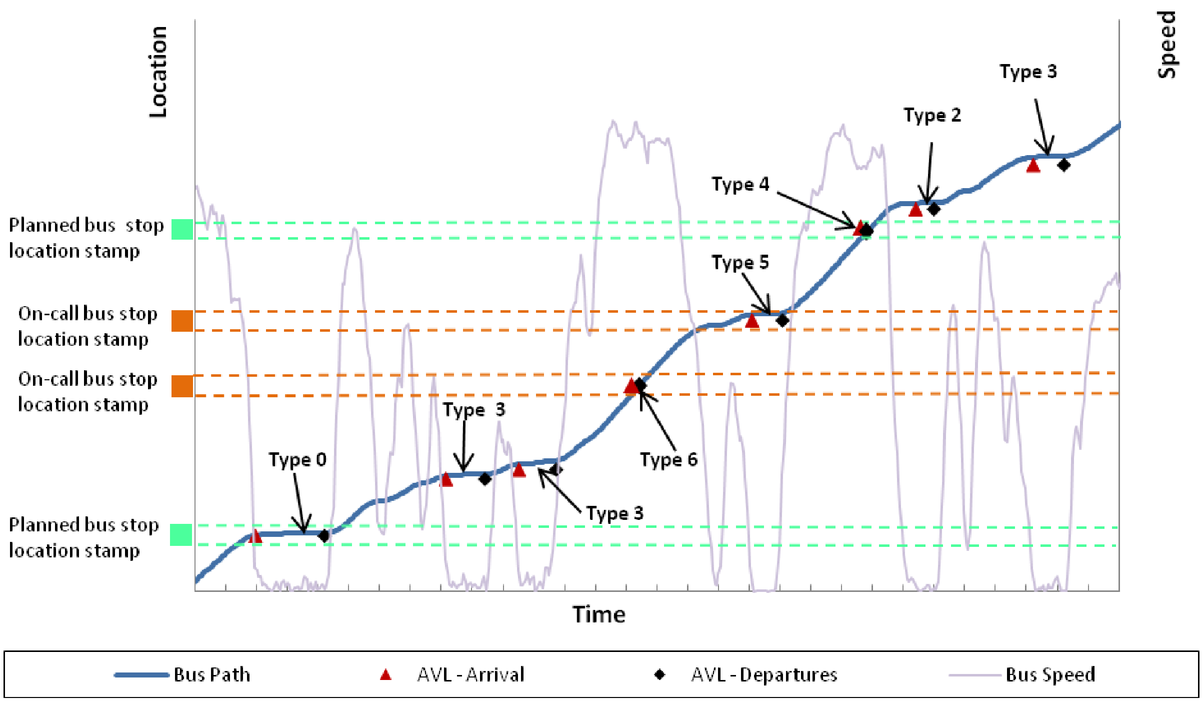


Figure 7. Schematic of how records in the GRT AVL/APC database are triggered

A comprehensive study led by Furth (2009) investigated the use of APC/AVL data by different transit agencies around the world. They found that the transit agency in Eindhoven in the Netherlands uses the amount of time spent at speeds below 5 km/h minus the time spent at stops to measure delay experienced by buses on route segments between every two consecutive scheduled stops. However, the Eindhoven method focuses only on quantifying delay but does not distinguish the (likely) causes for the delay (i.e. it does not attribute the cause of delays to a traffic control device, queue spill-back, mid-block interference, etc.).

2.1.2 Microscopic Simulation Method

With the development of computer technology, traffic flow theory including car following algorithms, lane changing algorithms, gap acceptance algorithms, etc. could be modeled in computer software packages. These packages provide the ability to simulate the movements of general purpose vehicles, transit vehicles and pedestrians, with a time step of between 1/10 to 1 second. Within these models, it is usually relatively straight forward to extract measures of delays because the model is able to trace the movements of every vehicle.

Consequently, micro-simulation models provide a platform within which researchers can conduct a wide range of analysis. One of the important applications is using simulation tool to evaluate performance of a road network (e.g. traffic corridor) or traffic control element (e.g. signal control) by estimating MOEs (e.g. mean delay, variation of delay and queue length etc).

Wong et al. (1998) developed a simulation model to investigate the effect of a bus stop upstream of an approach to a signal-controlled intersection. Field surveys were conducted on a number of typical sites to validate the simulation model. A good agreement between delays measured in the field and delays obtained from the simulation model was achieved.

Mousa (2003) devised a model using simulation software to emulate signalized intersection operation conditions and to estimate vehicular delays. This model is calibrated using a limited amount of field data including deceleration/acceleration distances, queue discharge headway, queue length, and vehicle trajectory. For validation, simulation was applied to an existing signalized intersection. The simulated delay is compared with a set of field observed delay. Statistical test results indicated that the proposed simulation model produces estimates of delay that are similar to those observed in the field.

The typical approach for applying micro simulation software is illustrated in Figure 8.

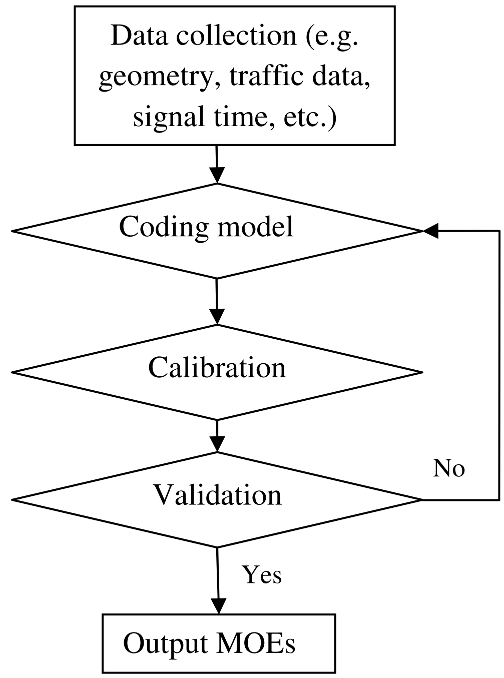


Figure 8. General procedure of microscopic simulation model

Although most simulators provide data input guidelines and default model parameters, these models nevertheless need to be calibrated for the specific study network and the intended applications (McNally 2005). Jones et al. (2004) indicates that micro-simulation models in general require fairly extensive data collection prior to network coding. This limits the spatial and temporal scope that can be considered.

2.1.3 Analytical Expressions for Quantifying Delay

There are a number of mathematical expressions which are used to estimate delay at signalized intersections. The most widely quoted one was proposed by Webster (1958) as seen in Equation (1).

$$d = \frac{C\left(1-\frac{g_e}{C}\right)^2}{2\left(1-X\frac{g_e}{C}\right)} + \frac{X^2}{2\lambda(1-X)} - 0.65\left(\frac{C}{\lambda^2}\right)^{1/3} X^{2+\frac{g_e}{C}} \tag{1}$$

Where:

X = volume-to-capacity ratio; ($X = \frac{\lambda}{C}$)
λ = volume of intersection approach (veh/h)
C = capacity of intersection approach (veh/h)
g_e = duration of effective green interval (s)

The original work by Webster forms the basis of most signalized intersection delay expressions in use throughout the world. For example, the HCM and Canadian Capacity Guide (CCG) methods are developed based on this work done by Webster. These equations provide an estimate of the average delay for all vehicles traversing the intersection approach that are making the same turning movement. The equations assume vehicles arrive at the intersection according to the Poisson process and that service times are deterministic. These models do not estimate the variation of individual vehicle delays nor can they reflect differences in delays to different vehicle types (e.g. transit vehicles) which may have different operating characteristics.

Fu et al. (2000) proposed an analytical model to estimate variability of delays and predict the variance of delays of vehicles traversing a signalized approach during a given time interval. This method considers situations under several assumptions such as a single through lane, unlimited space for queuing, constant saturation flow, arrival rate is constant, and etc. These assumptions are sufficiently restrictive that the application of the analytical model in practice is quite limited.

Several software tools are available which incorporate analytical expressions for the estimation of intersection delays (e.g. Synchro, HCS). These software tools enable the more efficient calculation of delays; however, the limitations of the underlying analytical expressions are still present, and these models require initial data collection efforts and professional software expertise as well. The most common data needed include intersection approach volume, signal timing plan and geometry of the intersection. The need for these data implies these software tools suffer (although to a lesser extent) from the same issue as micro-simulation models, namely that collecting these data is typically resource intensive.

2.2 Role of Measuring Signal Delay in TSP implementation

TSP is an operational strategy (e.g. early green, green extension, etc.) that facilitates the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections. TSP is used to reduce transit vehicle delays and tom improve schedule adherence while minimizing impacts to normal traffic operations.

The TSP Handbook (2005) indicates that consideration of TSP should begin with an assessment of traffic signal delay and its impact on transit travel times and reliability by taking field measurements or analyzing appropriate reports. Correspondingly, before TSP is implemented, planners should be aware of answers to the following key questions:

- Have transit vehicle delay data already been collected?
- If not, are alternative approaches/sources available to collect time-distance data and measure intersection delay (for example, current AVL/APC systems can provide distribution of running times by route segment, by time of data, and day-of-week that can be used to measure vehicle speed and intersection delay)?

Assessing the magnitude of intersection delay will be basis of evaluating the potential benefits that may be derived from TSP. This generally takes place during “before” study period.

Ron et al. (2006) proposed a framework for implementing TSP as shown in Figure 9. In the component "Existing Traffic Conditions", the level of service (LOS) of the intersection is input as an indicator of the magnitude of delay caused by the traffic signal.

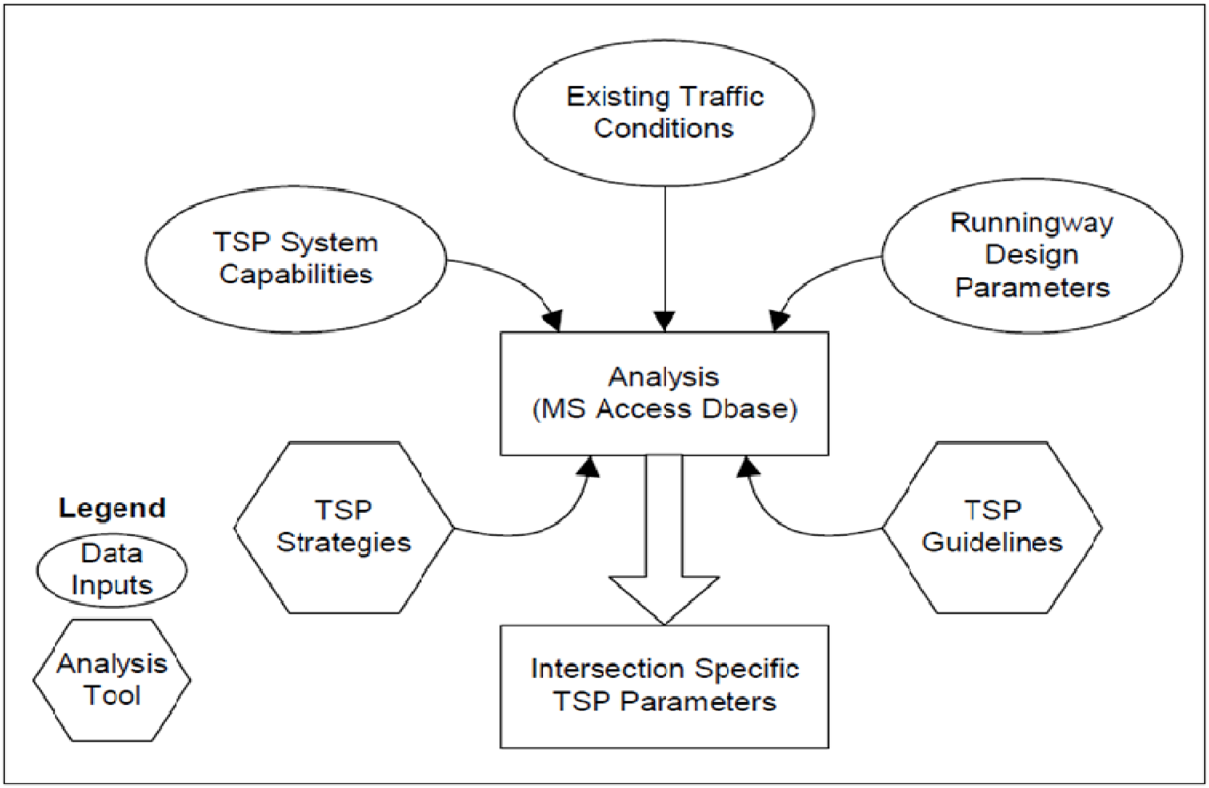


Figure 9. TSP decision-making process overview (Source: Ron et al. 2006)

In a report done by Chen et al. (2006), an arterial simulation model is developed to be used to evaluate the performance of signal priority strategy. Transit vehicle stop delays at signal intersections is one of measures of effectiveness (MOEs) used to analyze the improvement of operational performance after implementation of TSP in the simulation environment.

Pitu et al. (2001) devised an approach to integrate bus priority, traffic adaptive signal control and bus information/scheduling system together to improve quality of transit operations. Two networks are simulated to test the proposed algorithms. Bus delay is one of the measurements chosen to compare the performance of different signal control strategies.

Fargo-Moorhead Metro area transit signal priority report (2008) summarizes several evaluations of different transit signal priority projects conducted in different cities as shown below:

Evaluation of Transit Signal Priority Strategies for Small-Medium Cities, Fargo:

- 14% reduction in bus travel time
- 38% reduction in bus stop delay
- 14% increase in side-street person delay

Cermak Road Bus Preemption Study, Illinois:

- 8.2 sec/veh increase in cross-street stopped delay
- 83 sec (eastbound buses) and 12 sec (westbound buses) reduction in bus travel time
- 8% (eastbound buses) and 1% (westbound buses) reduction in bus travel time

King County Demonstration Project, Washington:

- 13% decrease (AM peak) to a 9% increase (midday peak) in non-transit traffic delay
- 34% (AM peak) and 24% (midday peak) reduction in intersection bus delay
- 8% reduction in bus travel time
- 13% decrease (AM peak) to a 8% increase (midday peak) in person delay

St. Cloud Transit Priority Evaluation Project, Minnesota:

- 43% reduction in bus delay caused by signalized intersections
- 24 bus riders were required to balance the person delay

From the literatures reviewed above, we can observe that delay measurements play a vital role in implementation of TSP strategies both in "before" study decision-making and "after" study evaluation. However, in most of these studies, delays are estimated using a simulation tool or on the basis of field measurements.

2.3 Conclusions

Delay measurements at signal intersections are important for decision making and therefore devising methods for measuring and estimating the quantities have been the focus of a great deal of research. One of applications of delay measurements at signal intersection is in TSP implementation. Cost effective methods for estimating delays could give transit agencies guidance to identify why and where TSP treatments are needed. However, most of these methods involve substantial labour and/or cost issues. With the increasing popularity of event-driven AVL/APC systems, transit agencies can utilize the methods described in the next chapter to directly estimate the transit vehicle stop delays resulting from signalized intersections.

Chapter 3: Methodology

This chapter presents the proposed method for determining transit vehicle stop delays at signalized intersections from archived AVL and APC data and describes the rationale underlying the proposed method.

3.1 Delays at Signalized Intersections – A theoretical description

The problem addressed in this thesis is that of estimating the delays that transit vehicles experience as a result of signalized intersections. In order to develop an appropriate estimation methodology it is important to first understand the operations of signalized intersections and the patterns of stopped delays that vehicles experience at these intersections. This section examines the expected delay patterns from a theoretical perspective.

Vehicles experience delays at signalized intersections as a result of the formation and dissipation of queues. We assume that we do not have information about the signal timings, vehicle arrival patterns, pedestrian volumes, etc. and therefore it is not possible to determine the actual queuing behaviour at the intersection. However, if we make the assumption that traffic demands during the analysis period are (relatively) constant and traffic signal timings remain (relatively) constant then on the basis of shockwave theory we can estimate the evolution of the queue that forms upstream of the traffic signal for both the under-saturated (demand on the approach is lower than the capacity of the approach) and over-saturated (demand exceeds the capacity of the approach) conditions. The patterns of stopped delays that result from these two conditions form the basis of the proposed methodology.

3.1.1 Under-saturated Conditions

Consider a signalized intersection approach that is operating in an under-saturated condition (Figure 10). The left hand graph in Figure 10 depicts the shockwave diagram. The y-axis represents distance from the stop-line of the signalized intersection approach. The x-axis represents time. The traffic signal timings associated with vehicles discharging from the approach are also shown on the x-axis. The solid blue lines represent shockwaves. During the red phase, no traffic is able to discharge and the arriving traffic must queue. As a result a backward moving congestion forming shockwave, representing the location of the tail of the queue, is created and moves upstream over time.

When the traffic signal turns green, vehicles are able to discharge at a rate equal to the saturation flow rate (which for the under-saturated conditions must be larger than the arrival rate λ) and consequently a backward moving recovery shockwave is created. This shockwave represents the front of the queue. The region between the forming and recovery shockwave is the stationary queue.

When the recovery shockwave (front of queue) intersects with the forming shockwave (tail of queue) then the queue is fully served and a third shockwave is formed. This is a forward moving shockwave and represents the boundary between the vehicles being served at the saturation flow rate and the arrival flow rate. When this shockwave intersects with the stop line, then we observe that the discharge flow rate drops from the saturation flow rate to the arrival flow rate.

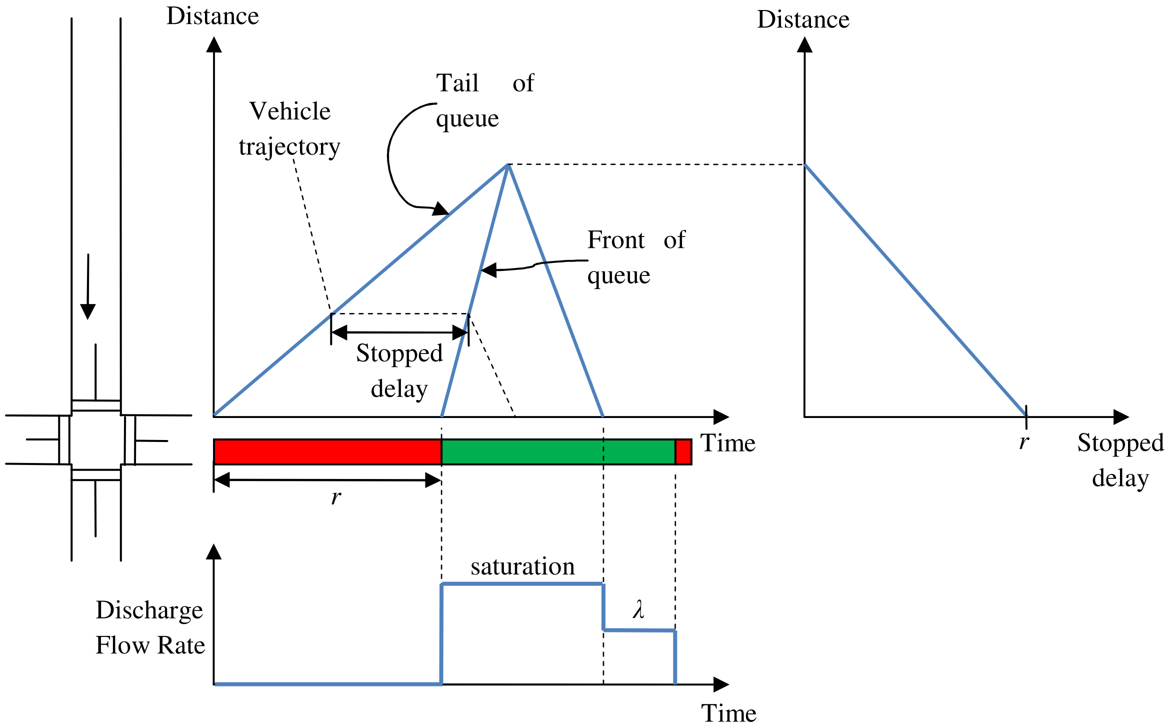


Figure 10. Queue pattern analysis using shockwave theory (under-saturated conditions)

The stopped delay that a vehicle experiences is determined as the horizontal line between the backward forming and backward recovery shockwaves and is a function of the time at which the vehicle arrives at the tail of the queue. An example vehicle trajectory is shown as the black dashed line.

It can be observed that the maximum stopped delay occurs when a vehicle arrives at the stop-line just when the signal turns red. Assuming the effective red time is denoted as r, then the vehicle must wait r seconds until the signal turns green again.

The minimum stopped delay occurs when a vehicle arrives at the tail of the queue just when the queue is entirely dissipated. If a vehicle arrives after the queue has dissipated but prior to the start of the next red interval, then it does not stop at all and experiences no stopped delay.

The right hand graph depicts delay and location of the stopped vehicle measured relative to the stop line. This graph indicates that we expect the largest stopped delays to be recorded close to the stop line and the magnitude of the stopped delays to decrease linearly as the stop location moves farther upstream.

We also note that the y-axis intercept of this relationship is a function of the volume (demand) to capacity ratio on the approach and the x-axis intercept is a function of the duration of the effective red time (Figure 11). We assume we don't know both these quantities (v/c and effective red duration) and therefore it is not possible to compute the equation of this line. Nevertheless, we use the knowledge that we expect transit vehicle stopped delays to follow such a relationship to assist in identifying the average transit vehicle delays.

We can also observe that the extent of the queues that form is a function of the volume to capacity ratio (v/c). As depicted in Figure 11, if the v/c ratio increases, the position at which a particular duration of stopped delay occurs moves upstream. Furthermore, if the duration of the effective red time changes then the intercept on the x-axis also changes.

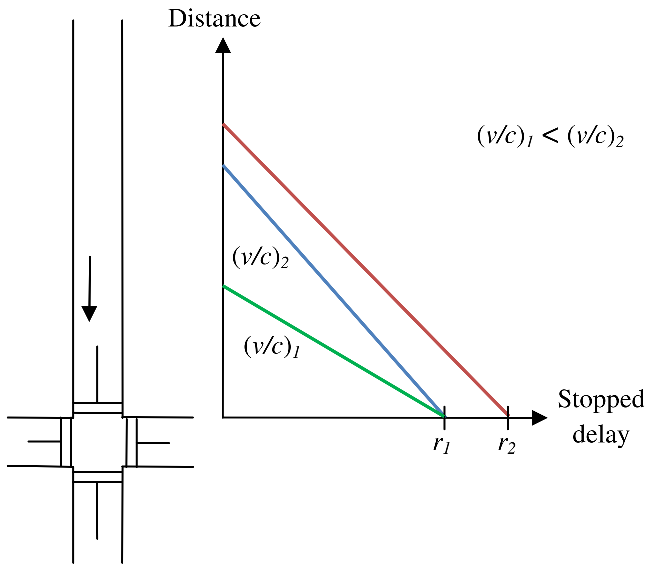


Figure 11. Expected impact of *v/c* and *r* on stopped delays

In Figure 10 we made the assumption that the arrival rate and signal timings remain constant over the analysis period and consequently the stopped delays are expected to fall on a straight line. However, in reality, we expect some variations to occur about this line as a result of:

- Changes in arrival rate during the analysis period
- Changes in the traffic signal timings
- The arrival traffic stream does not have uniform headways
- Variations in the traffic stream composition (e.g. vehicle length)
- Variations in vehicle operating characteristics (e.g. acceleration) of different vehicles
- Variations in driver behaviour
- Variations in the determination by the APC/AVL system of when a transit vehicle is stopped

Consequently, we expect to observe stopped delay data that look more like the data depicted in Figure 12. Please note that in the text that this figure is rotated versus Figures 10 and 11.

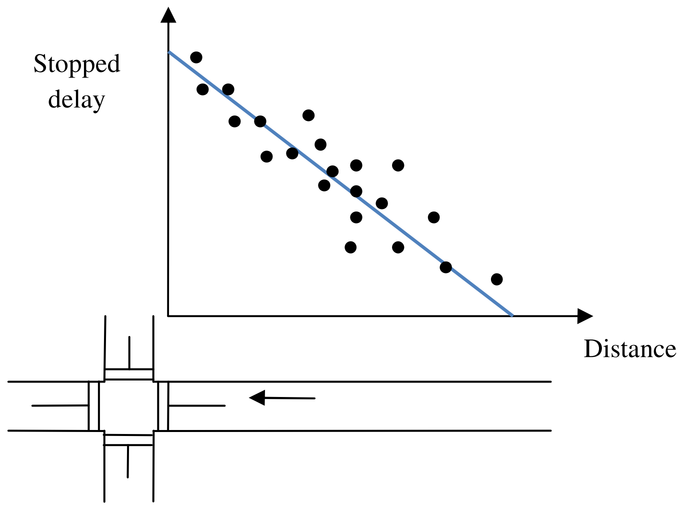


Figure 12. Stopped delay as a function of distance from intersection stop-line (under-saturated conditions)

3.1.2 Oversaturated Conditions

When an intersection is operating in an oversaturated condition, the queue that grows in one signal timing cycle is not fully dissipated during that same cycle. Consequently, the queuing pattern changes from cycle to cycle as shown in Figure 13. Figure 13 provides the same information as Figure 10 but for a condition when the signalized intersection approach is over-saturated. The most notable difference is that the queue that forms in the first red interval is not completely dissipated during the subsequent green interval and therefore the forward moving shockwave between the platoon being served at the saturation flow rate and the arrival flow does not intersect with the stop line. This means that some of the vehicles that joined the queue in the first cycle are not served in the first cycle and form an initial queue at the start of the red interval of the second cycle. As a result, a fourth shockwave with the same slope as former recovery queue is created by this over-saturation condition. The stopped delay experienced by vehicles in this queue would be close to *r*. The maximum queue length in the second cycle is longer than the maximum queue in the first cycle and therefore we observe a pattern of distance versus stopped delay (right-hand graph in Figure 13) in which a separate line is applicable to each cycle. For each subsequent cycle in which over-saturation conditions persist, the line is off-set to the upper right of the line for the previous cycle.

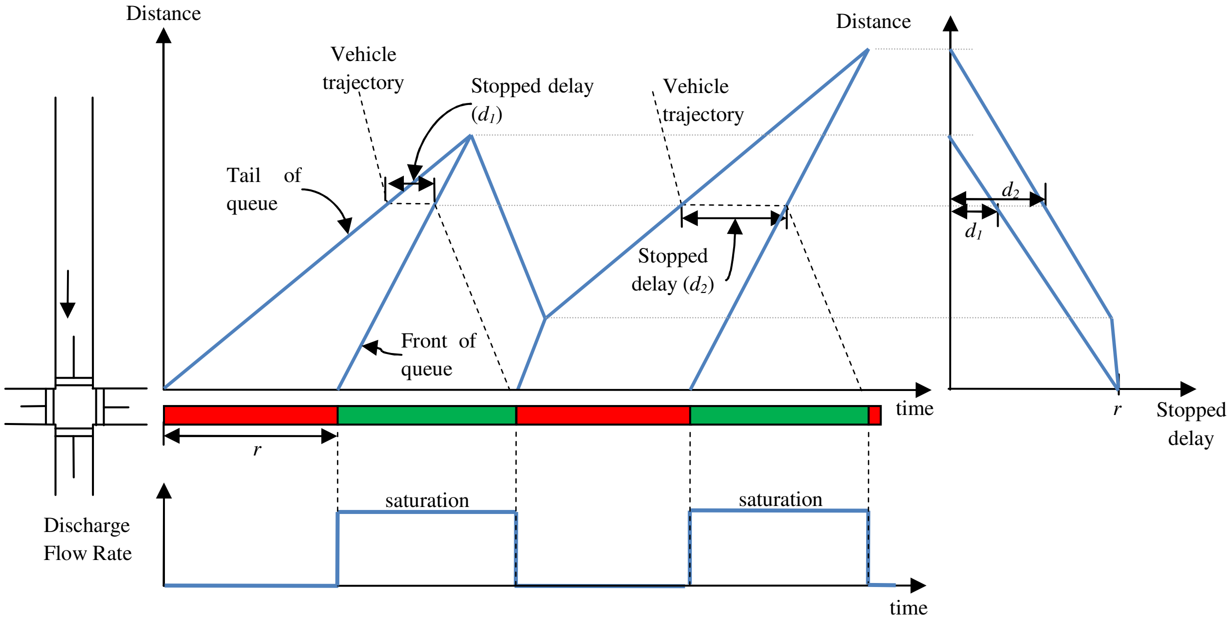


Figure 13. Queue pattern analysis using shockwave theory (over-saturated conditions)

With the same assumptions as made in Figure 10, we expect to observe stopped delay data that look more like the data depicted in Figure 14. Please note that in the text that this figure is rotated versus Figures 10 and 11.

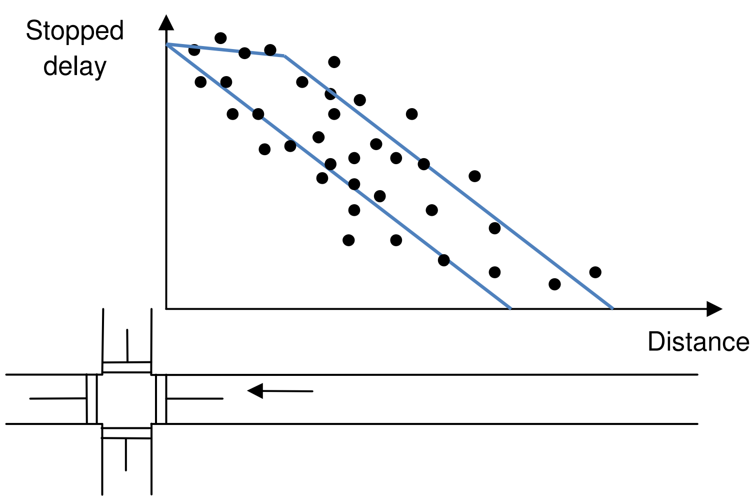


Figure 14. Stopped delay as a function of distance from the intersection stop line (over-saturated conditions)

3.2 Other Causes of Stopped Delays

The discussions above have assumed that all stopped delay occurrences result from the impact of queues at the signalized intersection. However, vehicles may experience stopped delays caused by traffic control devices or may be caused by other factors such as vehicles attempting to make parking manoeuvres, vehicles stopped in the travel lane (e.g. service vehicles), incidents, etc. These delays are not caused by the signalized intersections and therefore should not be considered when estimating the delays to transit vehicles caused by the signalized intersections.

The following section describes the proposed methodology.

3.3 Proposed Methodology

The proposed methodology is developed on the basis of the expected pattern of stopped delays caused by traffic signals as described in the previous section. In the proposed methodology, we assume that the only information available is:

1. Archived AVL/APC data containing stop event records for a sample of transit vehicles servicing a given route.
2. Route alignment.
3. Location of all signal control devices i.e. signalized intersections.

Other information, including the signal timings, traffic demands, presence of on-street parking, etc. is assumed to be not available. It is anticipated that the availability of these data may improve the accuracy of the estimates of transit vehicle delays caused by signalized intersections; however, in practice, these data are typically not available, and requiring these data would likely significantly limit the practical applicability of the proposed method.

Given these assumptions, the proposed method consists of the following three steps:

Step 1: Define route segments. Each route segment is bounded at the upstream and downstream ends by a signalized intersection.

Step 2: Obtain stopped delay occurring within predefined segments and associated distance from the downstream intersection stopline .

Step 3: Fit a boundary line to the data obtained in Step 2 classify the stopped delay occurrences. Data can be classified as:

Category 0: Unscheduled stop caused by a downstream traffic signal control.

Category 1: Unscheduled stop caused by random factors such as congestion, emergency vehicle, parking manoeuvres, stalled vehicle, bus breakdown, incident, etc.

Category 2: Unscheduled stop caused by other geometric (e.g. at-grade rail crossings) or traffic control (e.g. unsignalized intersections with stop or yield control) features.

Step 4: Compute the delay measurements (e.g. mean, variance, etc.) of the Category 0 transit vehicle stopped delays identified in Step 3.

Steps 1, 2 and 4 are straight-forward to carry out. Step 3 is described in more detail below:

3.4 Identifying Category 0 stopped delays

The basis of the proposed method for identifying Category 0 data from the set of all stopped delays is the signal stopped delay as a function of distance from the stop line pattern formed on the basis of the shockwave analysis described in Section3.1. In particular, we propose to identify the Category 0 delays by estimating a delay envelope boundary. The delay envelope boundary is represented by a piece-wise linear function as follows:

$$d = \begin{cases} d_{max} & 0 \leq x \leq X_{P1} \\ a + b\,x & x > X_{P1} \end{cases} \quad (a = d_{max}, b < 0) \tag{2}$$

Where:

x = Unscheduled stop location relative to stopline at downstream intersection (meters)

d_{max} = the maximum stopped delay which occurs when a vehicle stop at the stop line at the end of the green interval (seconds)

If $X_{P1} = 0$ then the delay envelope boundary is linear (having a form of $d = a + b\,x$) as depicted in Figure 15. For this situation, we consider that this intersection approach is operating in undersaturated conditions most times during the analysis period.

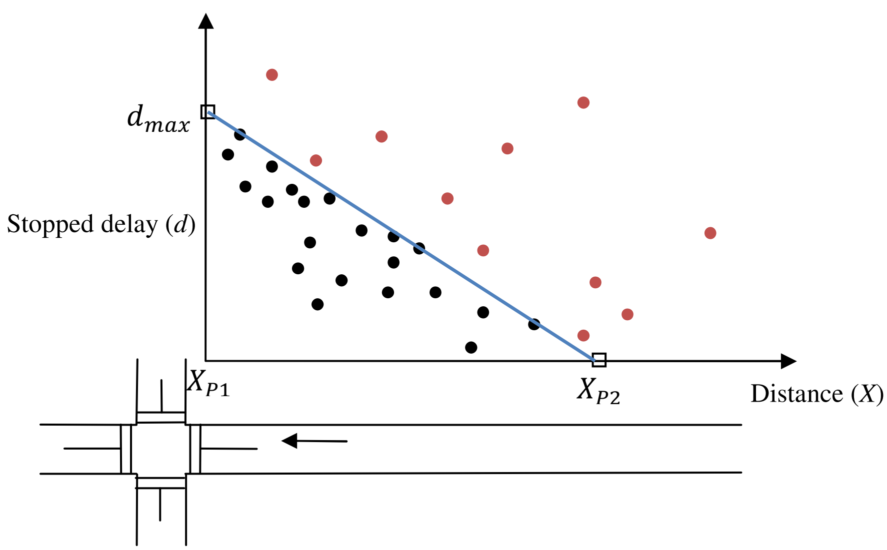


Figure 15. Delay boundary for determining Category 0 delay (undersaturated condition)

If X_{P1} is greater than zero, then the delay boundary envelope is piece-wise linear as depicted in Figure 16 and the assumption is that the intersection approach is operating in oversaturated conditions most times during the analysis period.

For both of these two situations, the Y axis intercept (i.e.d_{max}) represents the maximum delay experienced by a transit unit during a single stop event during the analysis period. The X axis intercept X_{P2} reflects that maximum extent of the horizontal queue that forms at the signalized intersection in the lane(s) that the transit vehicles on this route utilize during the analysis period.

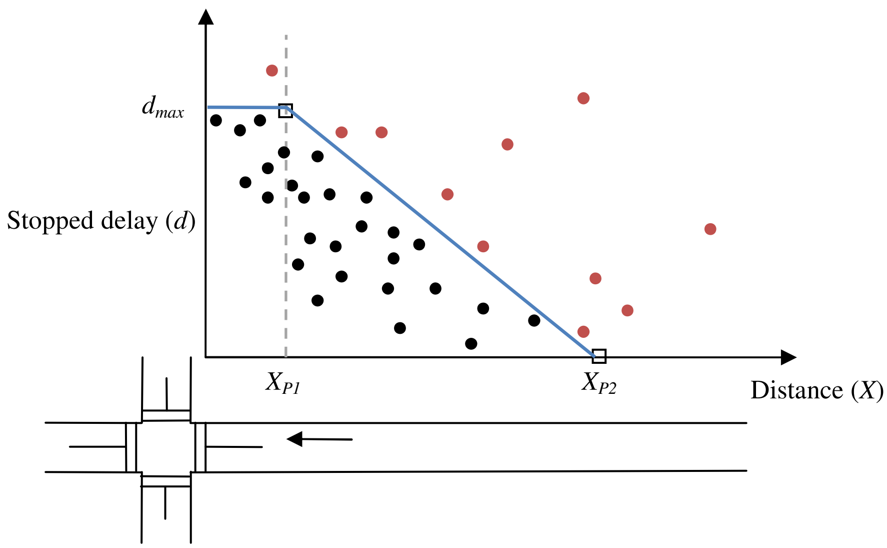


Figure 16. Delay boundary for determining Category 0 delay (oversaturated condition)

The parameters in the delay envelope boundary line formulation are found using the following approach which consists of 3 components:

1. The first step is to identify a solution space within which the delay envelope boundary line is contained. This solution space is defined as the space contained between two pivot lines ($\boldsymbol{x = X_P}$ *and* $\boldsymbol{y = d_{max}}$), the Y-axis, and the X-axis as shown in Figure 17.

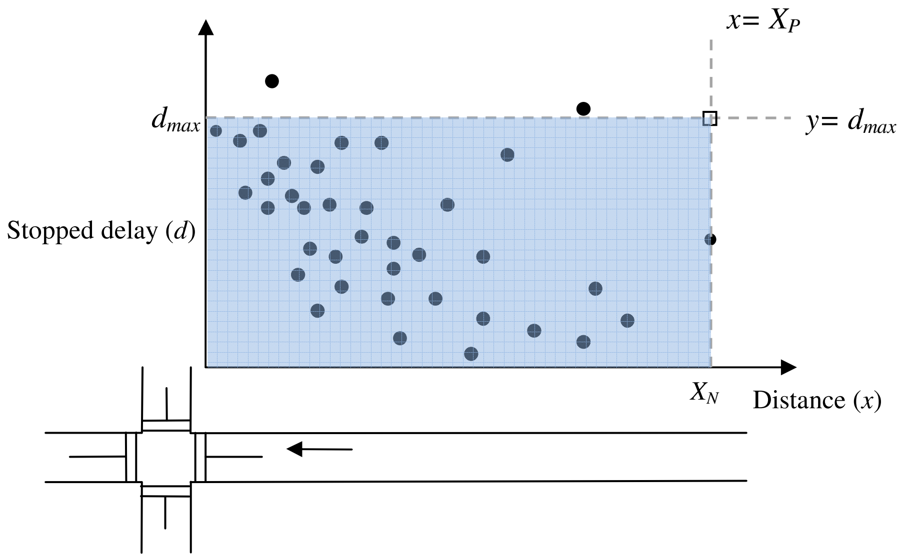


Figure 17. Determination of delay envelope solution space

X_P is computed as

$$X_P = min\begin{cases} X_{max} \\ X_N \end{cases} \tag{3}$$

Where:

X_{max} = maximum distance upstream of stop-line that queue is expected to reach (m)

X_N = x-axis coordinate of the most upstream observed stopped delay (m)

d_{max} is computed as a fixed percentile (P_{delay}) of a subset of all the stopped delay values. This subset of data is determined by sorting all of the stopped delay values in ascending order of their x value (where x represents the position measured relative to the stop-line) and then selecting the first n_d observations where n_d is computed as

$$n_d = max\begin{cases} NP_{obs} \\ N_{min} \end{cases} \tag{4}$$

Where:

N = total number of stopped delay observations on the route segment.

N_{min} = a constant reflecting the minimum number of observations to be considered for computing d_{max}.

P_{obs} = user defined percent ($0.0 < P_{obs} < 1.0$) used to determine the sub-set of stopped delay data for finding d_{max}.

2. Once the solution space is found we determine the optimal delay envelope boundary line within this feasible region.

   We do not find the slope of the boundary line through the use of linear regression because this would find some measure of central tendency and would result in many legitimate Category 0 points being misclassified as Category 1 or 2 points. Also, fitting a linear function presumes that the intersection approach is operating in an undersaturated state during the analysis period.

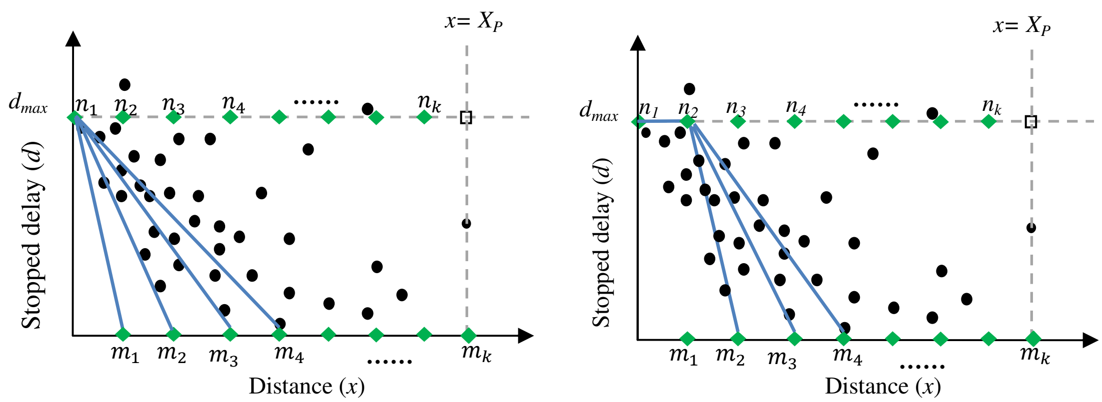
   Instead, a series of candidate boundary lines within the feasible region are evaluated. The set of candidate boundary lines is created by connecting "milepost" $\boldsymbol{n_i}$ and $\boldsymbol{m_j}$ as shown in Figure 18. The distance between every two horizontally consecutive mileposts is computed by Equation 5.

$$l = \frac{X_P}{k} \tag{5}$$

Where:

k = number of "milepost" on line $y = d_{max}$ or x axis;

$\boldsymbol{n_i (i = 1, 2, 3 \dots k)}$ is evenly distributed on line $\boldsymbol{y = d_{max}}$ from $\boldsymbol{(0, d_{max})}$ to $\boldsymbol{(X_P - l, d_{max})}$; $\boldsymbol{m_j (j = 1, 2, 3 \dots k)}$ is evenly distributed on the x axis from $\boldsymbol{(l, 0)}$ to $\boldsymbol{(X_P, 0)}$. For case (b) in Figure 18, $\boldsymbol{C_{i,j}}$ not only represents lines between $\boldsymbol{n_i}$ and $\boldsymbol{m_j}$ but also includes the horizontal line between $\boldsymbol{n_1}$ and $\boldsymbol{n_i}$.



(a) Undersaturated (b) Oversaturated

Figure 18. Candidate Delay Envelope Boundary lines

Based on our theoretical description of the distribution of the stopped delay observations, the slope of the boundary line is expected to be negative, and consequently only lines with negative slope are considered. Therefore a matrix of candidate delay envelope boundary lines can be obtained as shown in Table 2.

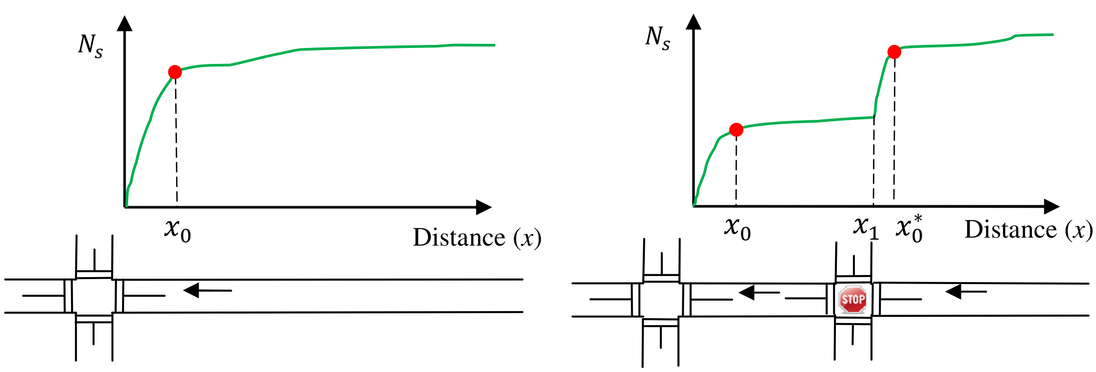
Table 2. Matrix of Candidate Delay Envelope Boundary Lines

	n_1	n_2	n_3	... ...	n_k
m_1	$C_{1,1}$	n/a	n/a	... ...	n/a
m_2	$C_{1,2}$	$C_{2,2}$	n/a	... ...	n/a
m_3	$C_{1,3}$	$C_{2,3}$	$C_{3,3}$	... ...	n/a
... ...	... ...	... ...	... ...	$C_{i,j}$	... ...
m_k	$C_{1,k}$	$C_{2,k}$	$C_{3,k}$	... ...	$C_{k,k}$

$C_{i,j}$ = candidate delay envelope boundary line as defined by Equation 2
n/a = no candidate line available as this combination does not satisfy the condition that the slope of the line is negative

3. Next, we need to determine which line within the set of candidate lines is the optimal delay envelope boundary line. If we assume that the analysis period duration is selected so that the

traffic demands and signal timings remain reasonably constant over the analysis period then we anticipate that the queue formation and dissipation over the different signal cycles maintains a reasonably consistent pattern. Therefore, variations in the magnitude of transit vehicle delay and the location at which the transit vehicle is stopped is primarily a function of when the transit vehicle arrives at the tail of the queue. If we have a relatively large number of observations and transit vehicle arrival times at the intersection are random, we anticipate the majority of stopped delay observations to reflect the linear trend expected from theoretical considerations. Consequently, points that are sparsely spaced, either in terms of position along the approach (x-axis) or in terms of magnitude of delay (y-axis) are assumed to result from causes other than the queue forming at the signalized intersection. Therefore, we expect the cumulative number of Category 0 stopped delay observations to increase relatively quickly as a function of distance from the stopline until the maximum extent of the queue. Beyond the location of the tail of the queue, transit vehicles are expected to stop less frequently and therefore the cumulative number of stopped delay observations should increase much less quickly. If the segment contains other geometric (e.g. at-grade rail crossings) or traffic control (e.g. unsignalized intersections with stop or yield control) features upstream of the signalized intersection, then these features could consistently cause Category 2 stopped delays. Consequently, the cumulative number of Category 2 stopped delay observations increases sharply as a function of distance from the stopline of traffic control feature or other geometric feature location until the maximum extent of the queue caused by these features. On the basis of this reasoning, we expect that the distribution of the cumulative number of stopped delay observations $\boldsymbol{N_s}$ as a function of distance $\boldsymbol{x}$ has a pattern as shown in Figure 19. The x coordinate of the red point represents the maximum extent of the queue caused by the signalized intersection or other geometric (e.g. at-grade rail crossings) or traffic control (e.g. unsignalized intersections with stop or yield control) features during the analysis period. $\boldsymbol{x_1}$ represents the stopline of traffic control feature or other geometric feature location.



i. Segment without other geometric characteristics in solution space

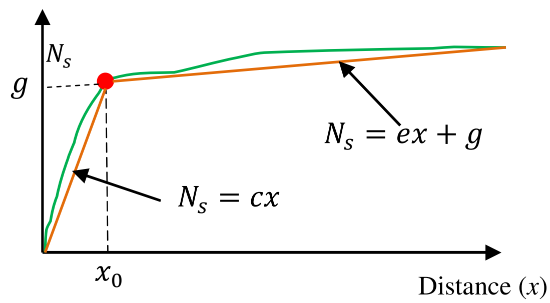
ii. Segment with other geometric characteristics in solution space

Figure 19. Distribution of cumulative number of stopped delay observations

In reality, the function $N_s = f(x)$ is nonlinear and is affected by a large number of factors, including transit vehicle arrival patterns, sample size, variations in traffic demands, variations in signal timings, capacity fluctuations resulting from sources other than signal timings, such as parking manoeuvres, etc. However, based on our analysis above, for scenario (i) in Figure 19 we assume $N_s = f(x)$ has the form

$$N_s = \begin{cases} cx & x < x_0 \\ ex + g & x \geq x_0 \end{cases} \tag{6}$$

where $c > 0, e > 0, g > 0$ as shown in Figure 20.



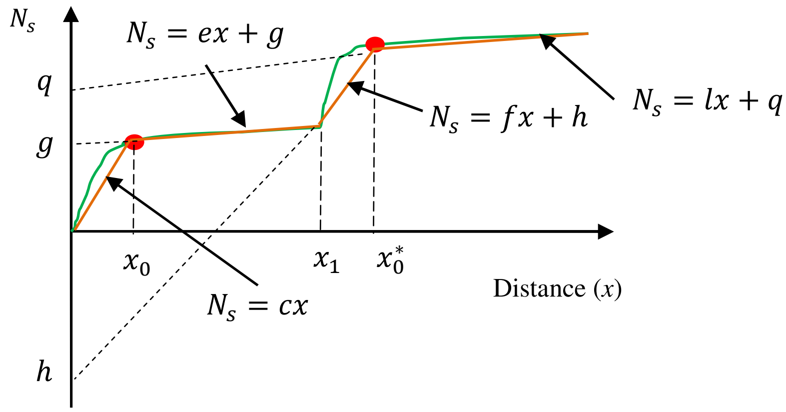
i. Segment without other geometric characteristics in solution space

Figure 20. Piece-wise linear distribution of cumulative number of stopped delay observations for scenario (i)

For scenario (ii) we assume $N_s = f(x)$ has the form

$$N_s = \begin{cases} cx & x < x_0 \\ ex + g & x_0 \leq x < x_1 \\ fx + h & x_1 \leq x < x_0^* \\ lx + q & x \geq x_0^* \end{cases} \tag{7}$$

where $c > 0, e > 0, g > 0, f > 0, h < 0, l > 0, q > 0$ as shown in scenario (ii) in Figure 19.



ii. Segment with other geometric characteristics in solution space

Figure 21. Piece-wise linear distribution of cumulative number of stopped delay observations for scenario (ii)

Then we define density of stopped delay observations as:

$$D = \frac{N_S}{A} \tag{8}$$

Where:

N_s = cumulative number of stopped delay observations as a function of location of unscheduled stopped delay

A = area defined by the delay envelope boundary line

For undersaturated conditions (i.e. Case a in Figure 18) the area A is computed as

$$A_{undersaturated} = 0.5xd_{max} \tag{9}$$

For oversaturated conditions (i.e. Case b in Figure 18) the area A is computed as

$$A_{oversaturated} = 0.5(x+o)d_{max} \tag{11}$$

Where:

o = distance (m) between n_1 and n_i.

For scenario (i), we substitute Equation 6, Equation 9 and Equation 10 into Equation 8 for each of the two cases depicted in Figure 18. For case (a) representing undersaturated conditions, we obtain

$$D = \begin{cases} \frac{cx}{0.5xd_{max}} & x < x_0 \\ \frac{ex+g}{0.5xd_{max}} & x \geq x_0 \end{cases} \tag{11}$$

The differential of D with respect to distance represents the change in the density and is computed as.

$$D' = \begin{cases} 0 & x < x_0 \\ -\frac{g}{0.5x^2 d_{max}} & x \geq x_0 \end{cases} \tag{12}$$

Note that from Equation 12, the minimum value for D' occurs when $x = x_0$.

For case (b) in Figure 18 (oversaturated conditions) we obtain

$$D = \begin{cases} \frac{cx}{0.5(x+o)d_{max}} & x < x_0 \\ \frac{ex+g}{0.5(x+o)d_{max}} & x \geq x_0 \end{cases} \tag{13}$$

We can compute the differential of D with respect to distance x as

$$D' = \begin{cases} \frac{co}{0.5(x+o)^2 d_{max}} & x < x_0 \\ \frac{eo-g}{0.5(x+o)^2 d_{max}} & x \geq x_0 \end{cases} \tag{14}$$

When examining Equation 14, we can observe that when $x < x_0$ $D' > 0$ as all the terms in the equation are positive. When $x \geq x_0$, the denominator of Equation 14 is always greater than zero. Evaluation of the numerator requires an estimate of the relative magnitudes of the three parameters e, o and g.

Since g is the Y-axis intercept of $N_s = ex + g$, this value is expected to be a close approximation of the total number of stopped delay records within the feasible region. Furthermore, this number is expected to be large when a large proportion of the transit fleet is equipped with AVL/APC equipment and data are acquired over a relatively large number of days. The value of e is expected to be quite small because it represents the slope of the cumulative number of observations as a function of distance beyond the tail of the queue. The value of o will not be larger than X_P which represents a reasonable maximum queue length (typically less than 500 meters). As a result, we expect $eo - g$ to be negative and therefore D' is expected to yield a minimum number at $x = x_0$.

For scenario (ii), we substitute Equation 7, Equation 9 and Equation 10 into Equation 8 for each of the two cases depicted in Figure 18. For case (a) representing undersaturated conditions, we obtain

$$D = \begin{cases} \frac{cx}{0.5xd_{max}} & x < x_0 \\ \frac{ex+g}{0.5xd_{max}} & x_0 \le x < x_1 \\ \frac{fx+h}{0.5xd_{max}} & x_1 \le x < x_0^* \\ \frac{lx+q}{0.5xd_{max}} & x \ge x_0^* \end{cases} \tag{15}$$

The differential of D with respect to distance represents the change in the density and is computed as.

$$D' = \begin{cases} 0 & x < x_0 \\ -\frac{g}{0.5x^2 d_{max}} & x_0 \le x < x_1 \\ -\frac{h}{0.5x^2 d_{max}} & x_1 \le x < x_0^* \\ -\frac{q}{0.5x^2 d_{max}} & x \ge x_0^* \end{cases} \tag{16}$$

Note that from Equation 16, the minimum value for D' is the smaller value between $D'(x = x_0)$ and $D'(x = x_0^*)$. If the minimum value of D' is obtained at $x = x_0$, then the maximum queue formed at the downstream signalized intersection does not spill back to the upstream geometric feature or other control device. However, if the minimum value of D' is obtained at $x = x_0^*$ then the maximum queue that forms at the downstream signalized intersection does spill back to the upstream geometric feature or other control device.

For case (b) in Figure 18 (oversaturated conditions) we obtain

$$D = \begin{cases} \frac{cx}{0.5(x+o)d_{max}} & x < x_0 \\ \frac{ex+g}{0.5(x+o)d_{max}} & x_0 \le x < x_1 \\ \frac{fx+h}{0.5(x+o)d_{max}} & x_1 \le x < x_0^* \\ \frac{lx+q}{0.5(x+o)d_{max}} & x \ge x_0^* \end{cases} \tag{17}$$

We can compute the differential of D with respect to distance x as

$$D' = \begin{cases} \frac{co}{0.5(x+o)^2 d_{max}} & x < x_0 \\ \frac{eo-g}{0.5(x+o)^2 d_{max}} & x_0 \le x < x_1 \\ \frac{fo-h}{0.5(x+o)^2 d_{max}} & x_1 \le x < x_0^* \\ \frac{lo-q}{0.5(x+o)^2 d_{max}} & x \ge x_0^* \end{cases} \tag{18}$$

Based on the analysis in examination of Equation 14, the value of $eo - g$ and $lo - q$ are expected to be negative. Consequently, the minimum value for D' is the smaller value between $D'(x = x_0)$ and $D'(x = x_0^*)$. If the minimum value of D' is obtained at $x = x_0$, then the maximum queue doesn't spill back to the upstream geometric feature or other control device. If the minimum value of D' is obtained at $x = x_0^*$, then the maximum queue spills back to the upstream geometric feature or other control device.

The above analysis suggests that the classification of the stopped delay observation (and therefore the identification of Category 0 delays) can be determined by finding the smallest change in density. Thus, we can select the delay envelope boundary line with the smallest change in density to find x_0 or x_0^* the location of the maximum extent of the queue. As a result, we make use of the notion that we want to position the delay envelope boundary line such that we **minimize the change in the density of stopped delay observations contained within the boundary line**.

Since we do not know the functional form of $\boldsymbol{N_s}$, we are unable to compute the differential to solve for $\boldsymbol{x_0}$ or $\boldsymbol{x_0^*}$. Consequently, we utilize a numerical method to find the optimal delay envelope boundary line. The area for every candidate delay envelope boundary line is computed by Equation 19

$$A = \frac{1}{2} d_{max}(X_{P1} + X_{P2}) \tag{19}$$

Where:

X_{P1} = x coordinate of n_i

X_{P2} = x coordinate of m_j

The slope of the boundary line is computed as

$$b = \frac{d_{max}}{X_{P1} - X_{P2}} \tag{20}$$

Where:

b = slope of the boundary line

Consequently, from Equation 19, the area created by boundary lines $\boldsymbol{C_{i,j}}$ as shown in Table 1 can be computed as

$$A_{i,j} = \frac{1}{2} d_{max}[(i-1) * l + j * l], where\ j \geq i \tag{21}$$

For each candidate boundary line C_{ij}, all stopped delay observations that fall below and to the left of the line are considered in computing the density $D_{i,j}$.

Then from Equation 8 the change in density between each pair of consecutive candidate boundary lines $C_{i,j}$ and $C_{i,j+1}$ can be calculated as

$$\Delta D_{i,j} = \frac{N_{i,j+1}}{A_{i,j+1}} - \frac{N_{i,j}}{A_{i,j}} \tag{22}$$

As a result, for every pair of consecutive candidate boundary lines $C_{i,j}$ and $C_{i,j+1}$ with same n_i, density change matrix could be obtained in Table 3.

Table 3. Density Change Matrix

	n_1	n_2	n_3	… …	n_{k-1}
m_2	$\Delta D_{1,2}$	n/a	n/a	……	n/a
m_3	$\Delta D_{1,3}$	$\Delta D_{2,3}$	n/a	……	n/a
m_4	$\Delta D_{1,4}$	$\Delta D_{2,4}$	$\Delta D_{3,4}$	……	n/a
… …	……	……	……	$\Delta D_{i,j}$	……
m_k	$\Delta D_{1,k}$	$\Delta D_{2,k}$	$\Delta D_{3,k}$	……	$\Delta D_{k-1,k}$

The boundary line that minimizes the objective function $\Delta \boldsymbol{D}_{\boldsymbol{i},\boldsymbol{j}}$ is selected. Based on Equation 2 and 20, we can obtain the optimal boundary line function as

$$d = \begin{cases} d_{max} & 0 \leq x \leq (i-1) * l \\ -\frac{d_{max} * j}{(i-j-1)} + \frac{d_{max}}{(i-j-1) * l} x & x > (i-1) * l \end{cases} \tag{23}$$

All points that fall below and to the left of the boundary line are used to compute the stopped delays associated with the signalized intersection.

3.5 Hypothetical Calculation Example

Since components 1 and 2 in the approach for determining parameters in the delay envelope boundary line described in previous section are straight forward, a hypothetical example is used to only demonstrate component 3 as shown in Figure 22. All black circle points represent unscheduled stopped delays occurred within this hypothetical route segment. The blue solid lines represent candidate boundary lines constructed on the basis of the method described in the previous section.

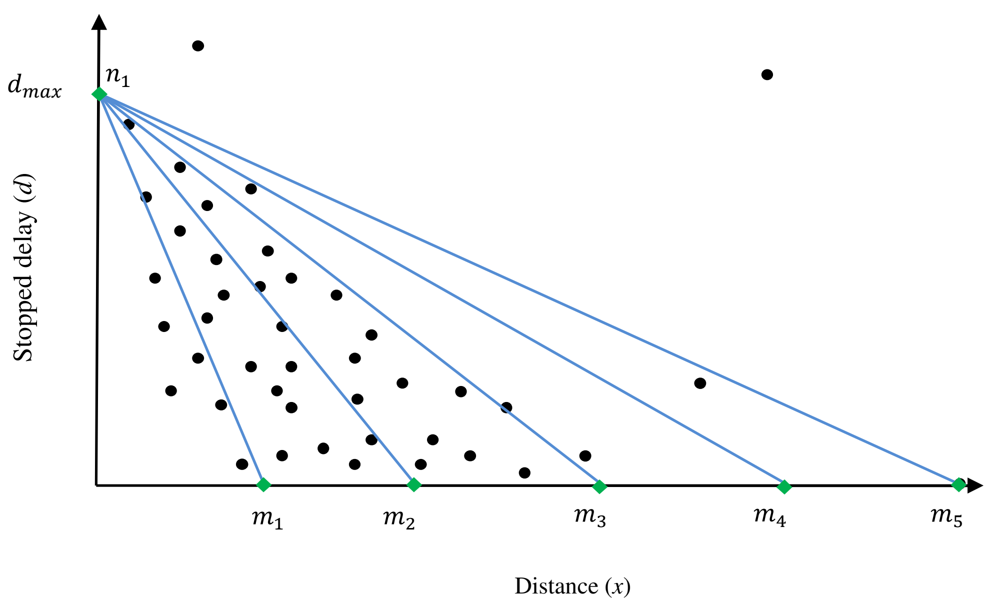


Figure 22. Hypothetical example

Based on components 1 and 2, d_{max}, X_P and l can be obtained based on data and input parameters. In this hypothetical scenario, we have $d_{max} = 50$ seconds, $X_P = 100$ meters, $k = 5$ and $l = 20$ meters. Then we take candidate lines with endpoint n_1 as an example. We can obtain all stopped delay observations that fall below and to the left of the candidate boundary line as shown in Table 4.

Table 4. Candidate boundary lines and associated cumulative observation number

$C_{i,j}$	$N_{i,j}$
$C_{1,1}$	6
$C_{1,2}$	20
$C_{1,3}$	36
$C_{1,4}$	39
$C_{1,5}$	41

Based on Equations 16 and 17, we obtain the change in density values as shown in Table 5.

Table 5. Density change calculation

$C_{i,j}$	$A_{i,j}$	$D_{i,j}$	$\Delta D_{i,j}$
$C_{1,1}$	$\frac{1}{2} * 50 * [(1-1) * 20 + 1 * 20] = 250$	$\frac{6}{250} = 0.024$	n/a
$C_{1,2}$	$\frac{1}{2} * 50 * [(1-1) * 20 + 2 * 20] = 500$	$\frac{20}{500} = 0.040$	$0.040 - 0.024 = 0.016$
$C_{1,3}$	$\frac{1}{2} * 50 * [(1-1) * 20 + 3 * 20] = 750$	$\frac{36}{750} = 0.048$	$0.048 - 0.040 = 0.080$
$C_{1,4}$	$\frac{1}{2} * 50 * [(1-1) * 20 + 4 * 20] = 1000$	$\frac{39}{1000} = 0.039$	$0.039 - 0.048 = -0.009$
$C_{1,5}$	$\frac{1}{2} * 50 * [(1-1) * 20 + 5 * 20] = 1250$	$\frac{41}{1250} = 0.033$	$0.033 - 0.039 = -0.006$

The minimum value of ΔD is obtained by candidate line $C_{1,4}$. As a result, based on Equation 23, the mathematical form of the optimal boundary can be determined as Equation 24.

$$d = 50 - 0.625\, x \tag{24}$$

This optimal boundary is shown in Figure 23.

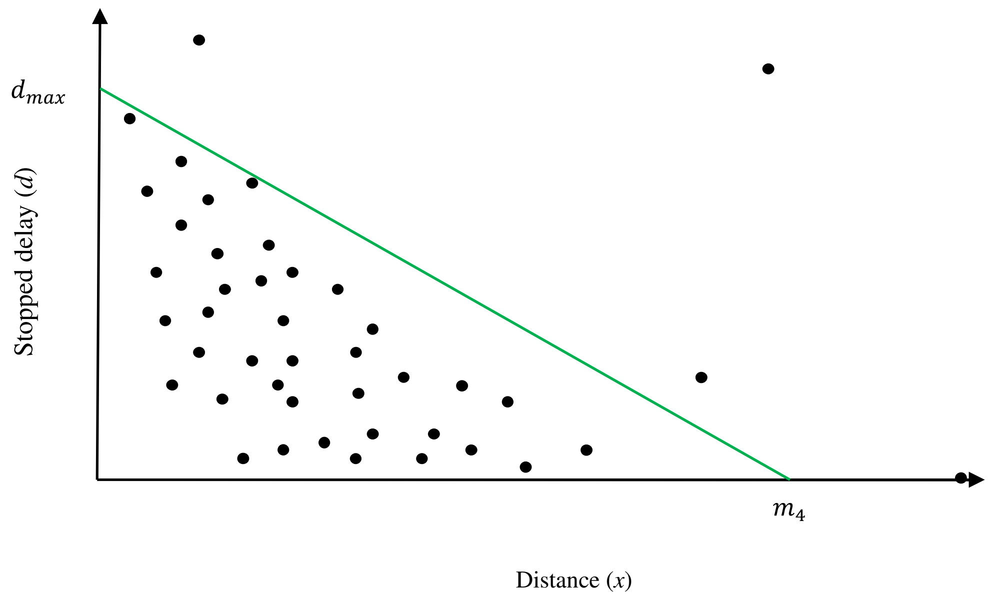


Figure 23. Optimal boundary line in hypothetical sample

In real calculation procedure, all candidate lines with different endpoints n_i are evaluated. The candidate line providing the smallest density change is considered as the optimal boundary line.

Chapter 4: Calibration and Validation

In this chapter the methodology presented in the previous chapter is calibrated and validated using field data. In particular, field observations of the locations of unscheduled transit vehicle stops are used to calibrate a model for determining transit vehicle stop locations (in terms of distance from the downstream stop line) as a function of the AVL/APC reported positions. Then the estimates of maximum queue length obtained from the proposed methodology are validated against field measurements.

4.1 Field Survey

4.1.1 Study Area

The calibration and validation field data were obtained in the Regional Municipality of Waterloo which is located in Southern Ontario, Canada as shown in Figure 24. In this area, Grand River Transit (GRT), a government agency, provides public transit services. GRT operates (as of 2011) a total of 232 buses of which 181 buses are outfitted with an AVL/APC system. Twelve of these buses were dedicated for the *iXpress* (Route 200) which is a limited stop express bus service running through a central corridor joining the three largest cities (Waterloo, Kitchener, and Cambridge) within the region. Six of these buses were dedicated for another *iXpress* (Route 201) which is also a limited stop express bus service running through a western corridor joining Waterloo and Kitchener. Bus headways on Route 200 are 10 minutes and 15 minutes on Route 201 during the peak periods. The 169 remaining buses are shared by other routes with varied headways during the peak periods. The GRT AVL/APC system stores stop level records consisting of information on arrival/departure times, odometer readings, longitude/latitude, stop type and more. When the AVL/APC equipped bus returns to the garage at the end of it runs, the recorded data are downloaded via a Wi-Fi link, matched with the associated schedule data, and stored in a database for later analysis.

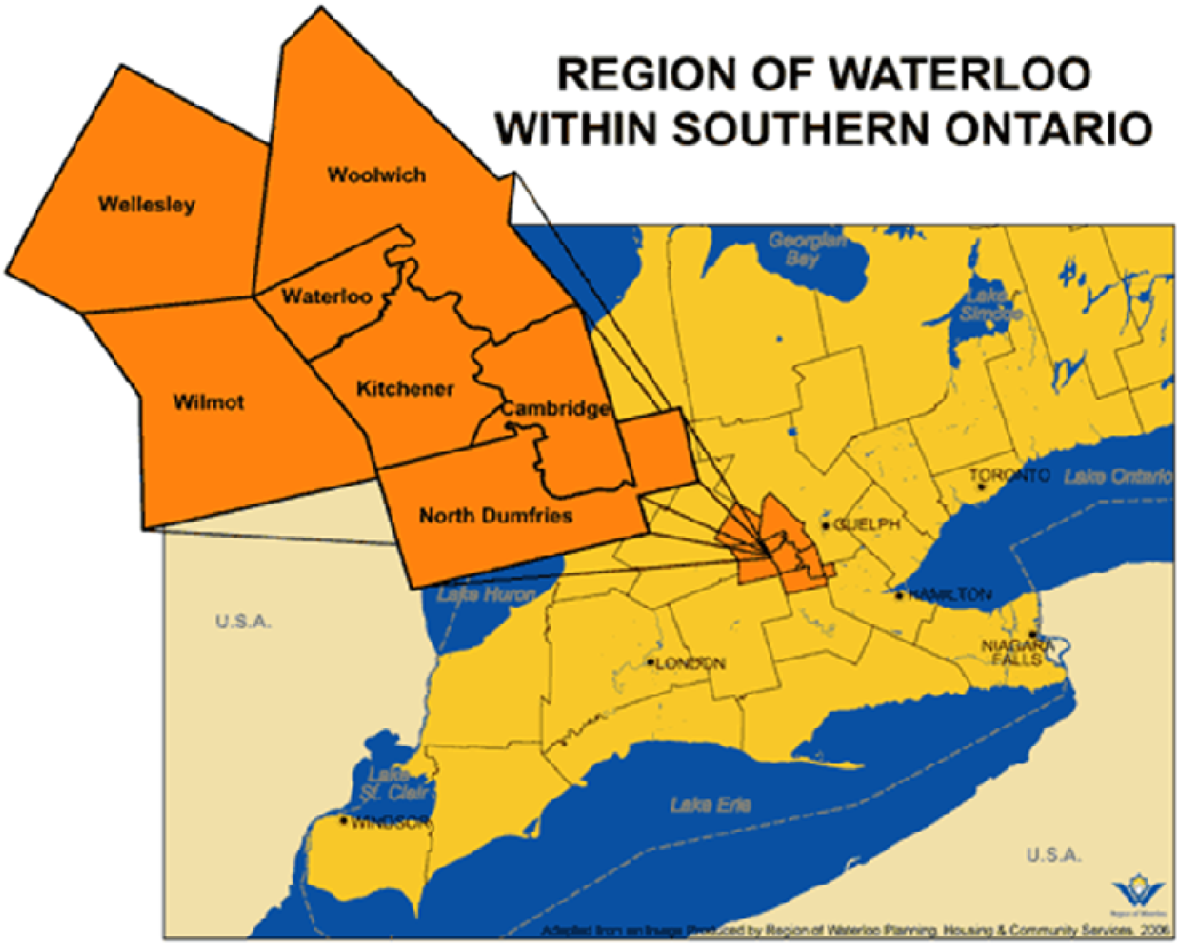


Figure 24. Region of Waterloo (Source:Waterloo Region,2006)

4.1.2 Field Data Collection

A dedicated field data collection survey was conducted on a 240 metre long bus route segment as shown in Figure 25. This segment is a section of westbound University Avenue in the City of Waterloo. The downstream boundary of the section is the signalized intersection of University Avenue and Seagram Drive. The upstream boundary of the section is a signalized pedestrian crossing and at-grade rail crossing (this intersection is labelled *Canada Trans Rail*). The westbound University Avenue approach at Seagram Drive consists of a dedicated left turn lane, an exclusive through lane, and a shared through and right turn lane. A 1m wide on-street bike lane is located on the right hand side of University Avenue along the entire section.

A nearside bus stop for Route 9 is located at the stopline. Five other bus routes also pass along this section of University Avenue (including *iXpress* Route 200, Route 7, Route 8, Route 12 and Route

29[1]) but all of these routes make a right turn movement at the intersection of University Avenue and Seagram Drive and do not stop to board or discharge passengers along the study section.

Field data were collected during the PM peak hour (determined as the period from 4:30PM - 6:00PM) on ten weekdays from October 3 to October 17. Two high definition video cameras were set up in on a pedestrian overpass to record traffic conditions along the study section as shown in Figure 25. One camera faced west to record queue lengths within the study section. The second camera faced east to identify situations when queue spilled back upstream of the location of the overpass (and therefore queues spilled back beyond the upstream boundary of the study section).

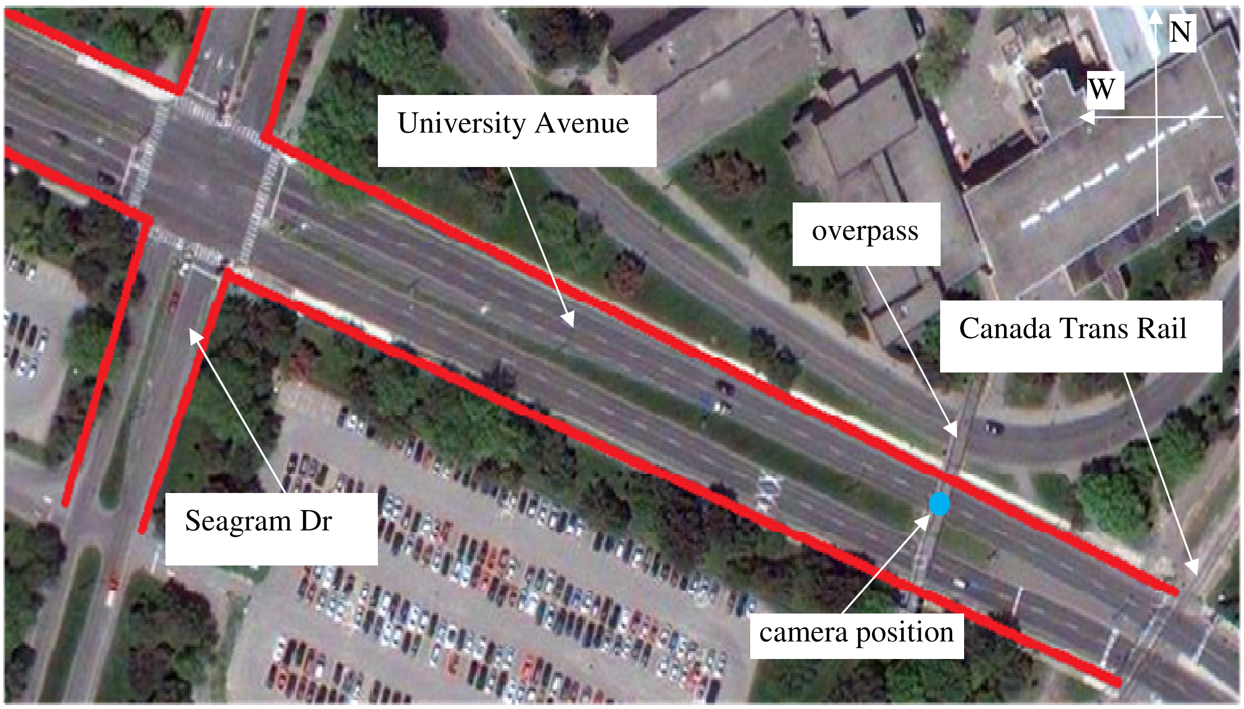


Figure 25. Field survey bus route segment (Source: Google satellite image)

Three categories of data were collected:

1. Transit vehicle unscheduled stop information (including time of stop, bus ID number, route, distance from stop line);
2. Maximum queue length data for the right-hand (shoulder) lane;
3. Transit vehicle travel time along this segment and its identification information including time entering and exiting the segment, route and observation date.

The unscheduled stop data were used to identify the corresponding AVL/APC records. These data were used to evaluate the accuracy of the stopped delay locations extracted from the AVL/APC data.

[1] These route numbers are given by GRT. For more information about these routes, please visit www.grt.ca

4.1.3 Field Data Extraction

The required measures were manually extracted from the recorded video. It is straightforward to obtain the bus identification information (i.e. bus ID number, route and time of occurrence) of unscheduled stop events as well as identification of the time as which each bus entered and departed this segment. The extraction of queue length, bus location when stopped and bus travel time along this segment was more involved.

Table 6. Cumulative distance of reference point (Background image source: Google satellite image)

#	Cumulative distance (meters)
0	0
1	11
2	18
3	27
4	35
5	46
6	54
7	63
8	72
9	81
10	90
11	99
12	108
13	117
14	126
15	135
16	144
17	155
18	163
19	172
20	190
21	199
22	208
23	217
24	226
25	235

The dashed central road marking lines appear within the video images and were used as reference point to indicate position (relative to the downstream stop line) when identifying the position of a stopped transit vehicle or measuring the maximum extent of the queue. As a result, based on these marking lines 26 points are chosen as location reference points. As shown in Table 6, point 0 represents the stopline and the other 25 points are located at the upstream end of each dashed lane striping line. The cumulative distance to the stopline from each of these 25 points was obtained using Google Earth distance measurement tool with the satellite image as the background. According to the definition of these reference points, one camera has a view from point 1 to point 18 and the other camera has a view beyond point 20. Points 19 and 20 are not visible to the cameras as they are located beneath the pedestrian overpass on which the cameras were located. Fortunately, the field observations indicated that the queue formed at the signalized intersection at Seagram Drive was very rarely located in this section and consequently, the influence on our field survey results is negligible.

Field queue lengths and unscheduled stopped delay event locations were measured by superimposing a grid overtop of the video image. This grid indicated the locations of reference points 1 through 25. At each point, a line passing through the point and parallel to the stopline was drawn. The position of the transit vehicle or queue was determined on the basis of these lines.

However since the video image has a trend to converge to one point as view goes further downstream, the distance between the reference lines becomes smaller and smaller the closer to the stopline (and farther from the camera). Consequently, for cases in which the observed queue length is short or position of bus in queue is close to the downstream stopline, it is difficult to identify the location on the basis of the reference lines. Therefore, for these conditions, we used the number of vehicles in queue to estimate the queue length and stopped bus location by calibrating a relationship between number of vehicles in queue and associated queue lengths. This relationship is developed only based on the cases in which the queue was observed to spill upstream of reference point 15 so that we are able to clearly identify the position and number of vehicles in queue. According to this description, situations of tail of queue or position of bus in queue could be categorized into the following four types:

Situation 1: Tail of queue or position of bus in queue is downstream of reference point 15;

Situation 2: Tail of queue or position of bus in queue is between point 15 and point 18;

Situation 3: Tail of queue or position of bus in queue is between point 18 and point 20;

Situation 4: Tail of queue or position of bus in queue is upstream of point 20.

Methods to extract field queue length and field bus unscheduled stop distance for each of these four situations are described below:

1. For **Situation 1**, we estimate field queue length and field bus unscheduled stop distance on the basis of the number of vehicles in the queue and the calibrated relationship between number of vehicles in queue and associated queue lengths;
2. For **Situation 2**, we utilize reference lines (e.g. pavement lane markings) to observe field queue length field bus unscheduled stop distance;
3. For **Situation 3**, we choose queue length as 163 metres which is the position of point 18;
4. For **Situation 4**, we utilize reference lines to observe field queue length or field bus unscheduled stop distance.

For **Situation 2**, **Situation 3** and **Situation 4**, methods to obtain queue length or field bus unscheduled stop distance consist of direct observation.

To deal with **Situation 1**, a linear regression model, in which the independent variable is the number of PCU (passenger car unit) in queue and the dependent variable is observed queue length, is developed based on 143 observations (i.e. **Situation 2** and **Situation 3** observations). Here, we assume that types of vehicle are categorized into two streams which are passenger car and heavy vehicle and we choose 1 heavy vehicle is equal to 2.25 PCU (Webster, 1966). As a result, the number of PCU in queue and its associated queue length are obtained. A sample of this kind of queue observations for a single lane is shown in Table 7. Others can be found in Appendix A.

Table 7. A sample of number of vehicles and related queue length

Observation Date	Observation #	Number of Passenger Cars in Queue	Number of Heavy Vehicles (truck and bus) in Queue	Number of PCU in Queue	Observed Queue Length (meters)
2011/10/3	1	14	0	14	135
2011/10/3	2	15	0	15	137
2011/10/3	3	17	1	19.25	162
2011/10/3	4	16	0	16	138
2011/10/3	5	17	0	17	150
2011/10/3	6	16	0	16	144
2011/10/3	7	17	0	17	163
2011/10/3	8	19	0	19	158
2011/10/3	9	17	0	17	163

The regression analysis showed that the intercept was not statistically significant and therefore was omitted and a second regression was calibrated in which the intercept was set to zero.

The regression results in Table 8 show that the slope is statistically significant and that almost 99% of the variation in the data is explained by the regression. Analysis of the residuals shows no unusual patterns.

The proposed prediction model is

$$Y_0 = 8.0X_0 \tag{25}$$

Where:

Y_0 = predicted queue length

X_0 = number of PCU in queue

Table 8. Result of queue length regression

Regression Statistics	
Multiple R	0.994
R Square	0.989
Adjusted R Square	0.983
Standard Error	15.727
Observations	143

	Coefficients	Standard Error	t Stat	P-value
X_0 = number of PCU in queue	8.0	0.1	116.1	0

The coefficient for 8.0 implies that each PCU occupies 8m of roadway when in a stopped queue. This value includes the length of the vehicle and the separation distance between the rear bumper of the next downstream vehicle and the front bumper of the current vehicle. To provide context, this value implies a jam density (the density of the traffic stream in a stopped queue) of 125 PCU/km. This value is consistent with engineering expectations.

Equation 25 can be used to determine queue length for **Situation 1** cases and therefore the queue length for all four situations can be determined. A sample of observed queue length on Oct 3, 2011 is shown in Figure 26. The complete set of observed queue length data can be found in Appendix B.

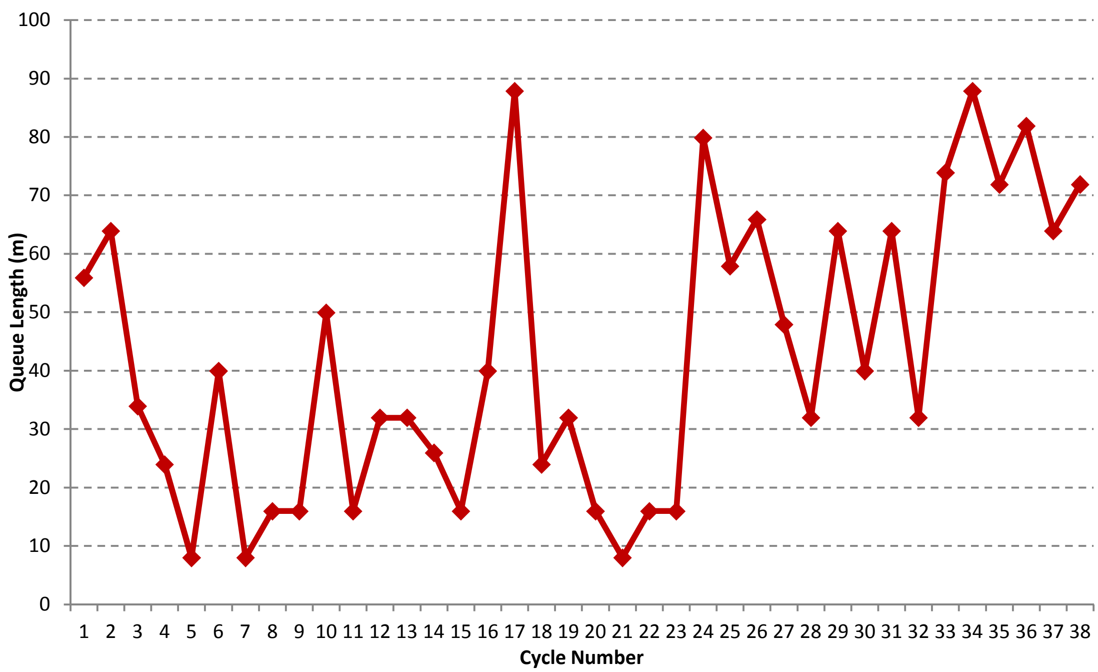


Figure 26. Observed queue length on Oct 3, 2011

During three of the field data collection period (Oct 5, Oct 6 and Oct 12, 2011) construction or severe weather occurred which caused unusually large queues. These conditions are not expected to occur frequently and therefore are not representative of typically queue conditions. Furthermore, given that field data were only collected over 10 weekdays the inclusion of these 3 non-typical days will have a significant influence on aggregated measures. As a result, the data from these three days were not considered when calculating the aggregate measures of the queue during the PM peak period (Table 9).

Table 9. Field queue measurements

Queue measurements(meters)	
Average	43.7
95% Percentile	105.9

Based on Equation 25 the locations of observed unscheduled stopped delay events were obtained. A sample of these data is provided in Table 10. The complete set of field data is provided in Appendix C.

Table 10. A sample of locations for observed unscheduled stopped stop delay events

Date	Route	Time	Number of vehicles downstream of bus				Position measured by reference lines (metres)		PCU	Distance of bus to stopline (meters)
			Passenger cars		Heavy vehicles					
			Left lane	Right lane	Left lane	Right lane	Left lane	Right lane		
2011/10/3	29	16:35		0		0			0	0.0
2011/10/3	8	16:50		4		0			4	32.0
2011/10/3	9	16:57		0		0			0	0.0
2011/10/3	8	17:17		2		0			2	16.0
2011/10/3	200	17:20		2		0			2	16.0
2011/10/3	29	17:36		0		0			0	0.0
2011/10/3	7	17:42		5		0			5	39.9

For extracting bus travel time along this segment, an entry bar and exit bar are set as shown by Figure 27. The entry bar is located at the upstream boundary of the study segment. The exit bar is located at the stopline at the downstream intersection. The time at which each transit vehicle crossed the entry and exit bars was recorded along with the unique identification number of each transit vehicle. The travel time of each transit vehicle was computed as the exit time minus the entry time.

Figure 27. Entry bar and exit bar within field segment

A sample of the observed bus travel time and its identification information is shown in Table 11. The complete set of this data is provided in Appendix D.

Table 11. A sample of the observed bus travel time along field segment

Date	Route	Entry Time	Exit Time	Actual Travel Time(s)
2011/10/3	7	16:40:06	16:40:37	31
2011/10/3	7	17:41:50	17:42:41	51
2011/10/3	8	17:18:57	17:20:26	89
2011/10/3	200	16:45:19	16:45:56	37
2011/10/3	200	17:21:03	17:22:15	72
2011/10/3	200	17:31:33	17:31:54	21
2011/10/4	7	16:42:33	16:43:18	45
2011/10/4	7	17:10:12	17:10:30	18
2011/10/4	8	16:46:55	16:48:03	68
2011/10/4	12	16:44:33	16:44:52	19

4.2 Methodology Calibration and Validation

4.2.1 AVL/APC Bus Unscheduled Stop Distance Calibration

The proposed methodology is developed according to a relationship between unscheduled stopped delays and associated distance from stopline at the downstream signalized intersection. Distance to the stopline is computed by calculating the distance from the recorded stop location (i.e. the latitude and longitude recorded by the AVL/APC system) to the downstream signalized intersection stopline. This distance is computed within the ArcGIS desktop environment following the street centrelines to the intersection centre point. It is necessary to compare the distances obtained in this manner to the distances observed in the field data.

The previous section described how the distances to the stopline were extracted from the observed field data. These distances are matched with AVL/APC bus unscheduled stop distance based on time and route information. A linear regression model, in which the independent variable is AVL/APC bus unscheduled stop distance and the dependent variable is field observed distance, is developed based on 44 paired observations as shown in Figure 27.

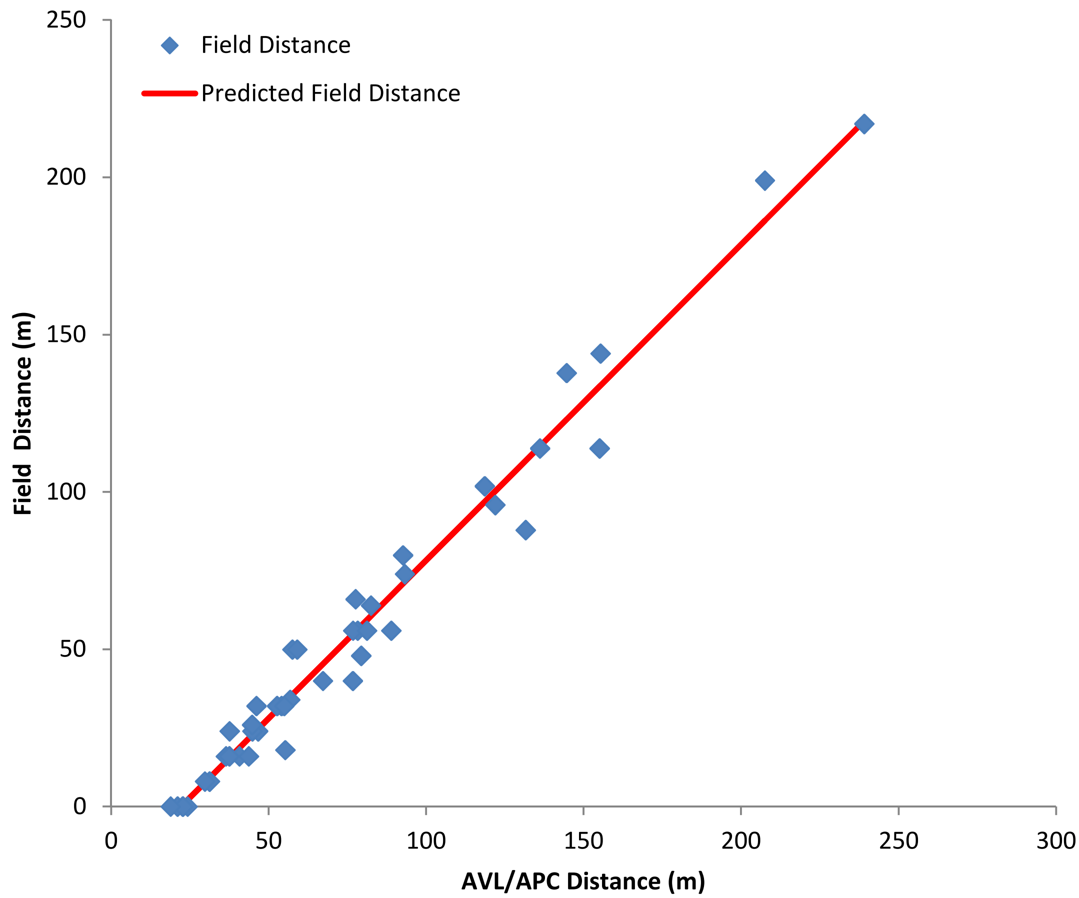


Figure 28. AVL/APC bus unscheduled stop distance VS. Field bus unscheduled stop distance

The regression results in Table 11 show that both the slope and intercept are statistically significant and that almost 97% of the variation in the data is explained by the regression. Analysis of the residuals shows no unusual patterns.

The proposed prediction model is

$$Y_1 = 1.0X_1 - 22.2 \tag{26}$$

Where:

Y_1 = predicted bus unscheduled stop location (m)

X_1 = AVL/APC bus unscheduled stop location (m)

Table 12. Predicted stop distance regression analysis result

Regression Statistics	
Multiple R	0.987
R Square	0.973
Adjusted R Square	0.973
Standard Error	8.31
Observations	44

	Coefficients	Standard Error	t Stat	P-value
Intercept	-22.2	2.3	-9.8	0
AVLAPC_Distance	1.0	0.03	39.5	0

The non-zero intercept indicates that there is a constant bias between the distances obtained from the AVL/APC data and the field observations. This bias can be explained using Figure 28.

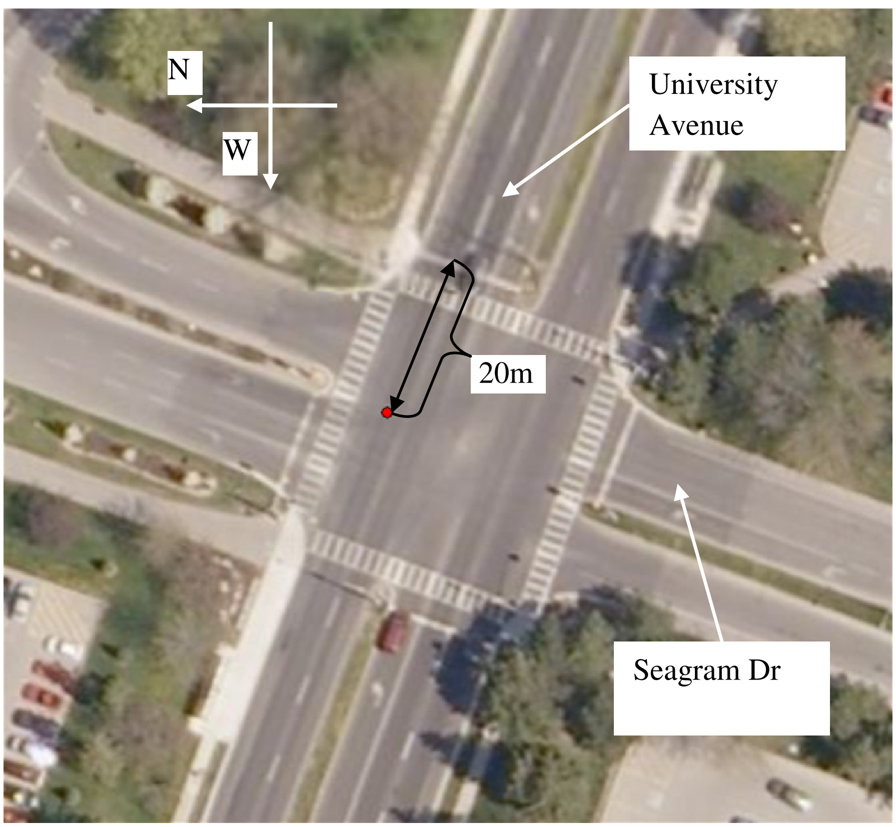


Figure 29. GIS representation of the location of the intersection versus the location of the stopline (Source: Google satellite image)

In Figure 28, the red point represents the location of the signalized intersection as defined within the GIS database. From Figure 28, it can be seen that this point represents a location near to the centre of intersection. However, in the proposed method, the distance associated with the location of a transit vehicle stopped delay event is measured to the stopline, not the centre of the intersection. The difference between the location of the centre of the intersection within the GIS database (i.e. the red point in Figure 28) and the stopline for the westbound approach is approximately 20 metres. Consequently, the intercept in Equation 26 corrects for this difference. Therefore, queue length estimated by the proposed method should be adjusted by subtracting the constant intercept in Equation 26. Then the estimated value can be compared with field queue observations to validate the method. The validation is provided in the Section 4.2.3.

4.2.2 AVL/APC Bus Unscheduled Stopped Delay Calibration

The AVL/APC system captures bus stopped delay rather than total delay (where total delay is equal to stopped delay plus acceleration and deceleration delay). Consequently, it is necessary to examine the proportion of the total delay associated with stopped delay. Observed total delay is estimated as the actual travel time minus the free speed travel time. Free speed travel time is calculated as the distance between the entry bar and exit bar divided by the assumed free speed. The distance between the entry and exit bars is simply the length of study segment which is 240 metres. The posted speed limit on University Avenue is 50km/h and is assumed to be the free speed. Consequently, the free travel time is 17.3 seconds.

Forty-four transit trips recorded in the AVL/APC system were matched with field observations. A sample of stopped delays of these trips within field segment and the associated field delay are shown in Table 13. The complete data set is provided in Appendix E.

Table 13. A sample of AVL/APC stopped delay vs. observed total delay

Stop ID[1]	Trip ID[2]	Date	Route	AVL/APC Stopped Delay(s)	Observed Total Delay(s)
78913371	78913344	2011/10/3	7	4	13.7
78913452	78913420	2011/10/3	7	15	33.7
78790921	78790915	2011/10/3	8	60	71.7
78872433	78872373	2011/10/3	200	0	19.7
78859814	78859761	2011/10/3	200	45	54.7
78778678	78778627	2011/10/3	200	2	3.7
79028970	79028940	2011/10/4	7	2	27.7
79025443	79025419	2011/10/4	7	0	0.7
79024138	79024130	2011/10/4	8	38	50.7
79020413	79020373	2011/10/4	12	0	1.7

[1] Unique id for bus stop event which is given by the GRT AVL/APC system. Please refer to introduction in section 5.2 for more details.
[2] Unique id for bus trip which is given by GRT AVL/APC system. Please refer to introduction in section 5.2 for more details.

Based on these 44 observations, two linear regression models were developed. In each case the dependent variable is the predicted total delay and the independent variable is the AVL/APC delay. The first model included two coefficients, the intercept and slope. The second model assumed the intercept was zero and therefore included only a single coefficient, the slope. Results show that the coefficients in both models are statistically significant. However, the second model, in which the intercept was set to zero explains more of the variations in the observed data. This prediction model is

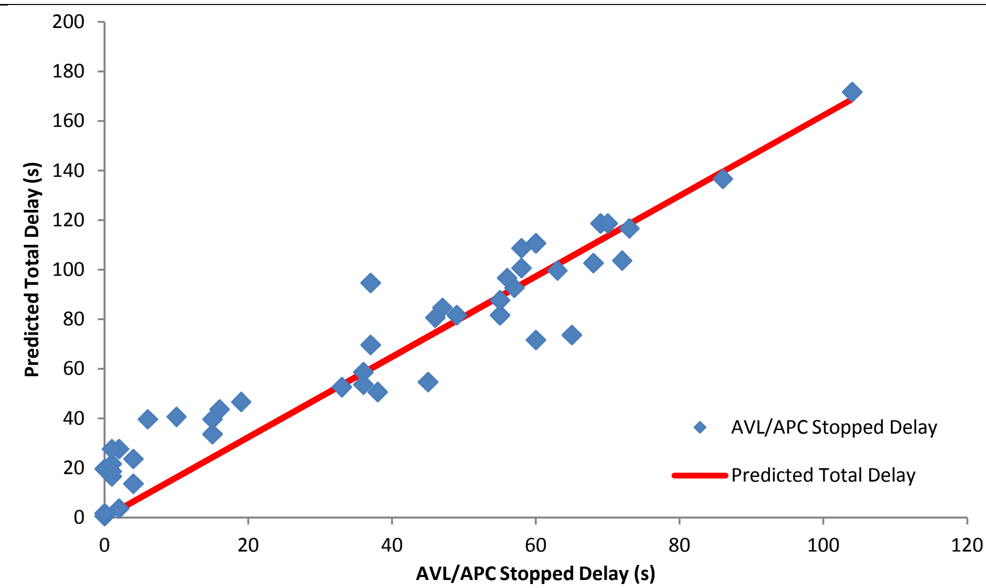
$$Y_3 = 1.6X_3 \tag{27}$$

Where:

Y_3 = predicted total delay (seconds)

X_3 = AVL/APC stopped delay (seconds)

Table 14. Predicted total delay regression results



Regression Statistics	
Multiple R	0.981
R Square	0.963
Adjusted R Square	0.939
Standard Error	15.056
Observations	44

	Coefficients	Standard Error	t Stat	P-value
AVL/APC stopped delay	1.6	0.05	33.3	0

From the Table 14, it can be seen that the proposed regression model explains 96% of the variations in the data. The slope coefficient of 1.6 implies that stopped delay constitutes approximately 62.5% of total delay. The remaining delay is associated with acceleration and deceleration delay and travelling at a speed less than the free speed.

Based on the result of this regression, it is suggested to use the proposed method to estimate stopped delays and then to use the regression (Equation 27) to estimate total delay from the stopped delay.

4.2.3 Validation of the Maximum Queue Lengths Estimated by the Proposed Method

The proposed method was applied to the AVL/APC data which was recorded during the same period of time when the field survey was conducted. This set of AVL/APC data is provided in Appendix F. The proposed method requires the specification of several parameters. The selected values are shown in Table 15.

Table 15. Input parameters for application in validation scenario

Parameters	Value
N_{min}	10
P_{obs}	5%
P_{delay}	99%
X_{max}	500 metres
k	8,10,12,14,16,18,20,22,24

According to the description of the proposed methodology provided in the previous chapter, k is the most important parameter. To obtain reliable delay and queue estimation from method, an appropriate value of k should be chosen. Consequently, a sensitivity analysis was conducted to determine which value to select. The results of this analysis are provided in Table 16.

Table 16. Result of method application on field segment

Num of Bin(k)	Bin Size (meters)	Adjusted queue Length (minus constant 22.2)	Error (Adjusted – 95% Percentile Observed Queue Length)(m)
8	26.6	84.2	-21.6
10	21.2	84.2	-21.6
12	17.7	84.2	-21.6
14	15.2	114.6	8.7
16	13.3	110.8	4.9
18	11.8	84.2	-21.6
20	10.6	9.9	-96.0
22	9.7	55.3	-50.6
24	8.9	31.1	-74.7

Note that the values in Column 3 in Table 16 are obtained by subtracting the constant of 22.2m (as obtained from Equation 26) from the queue length estimates obtained from the AVL/APC data.

From Figure 30 and Figure 31, it can be seen that when the bin size is approximately 13 (or approximately 1.5 times the length of a PCU), the error is minimized. As bin size decreases, the estimation error becomes more sensitive to length of bin. This is expected, because considering length of vehicle, position of bus in queue in terms of distance to the stopline is not really a continuous value even if there is large sample size (i.e. the value is likely to be integer multiples of the length of a PCU). As a result, if the bin size is quite small, there may not be any observations within a bin even if this bin is close to the downstream intersection and sample size is fairly large. Consequently, an appropriate bin size should be chosen so that bin can continuously represent signal delay condition over distance to downstream intersection. Considering calculation convenience, 15 m (or approximately 2 times the distance headway of a single PCU in a stopped queue) is recommended.

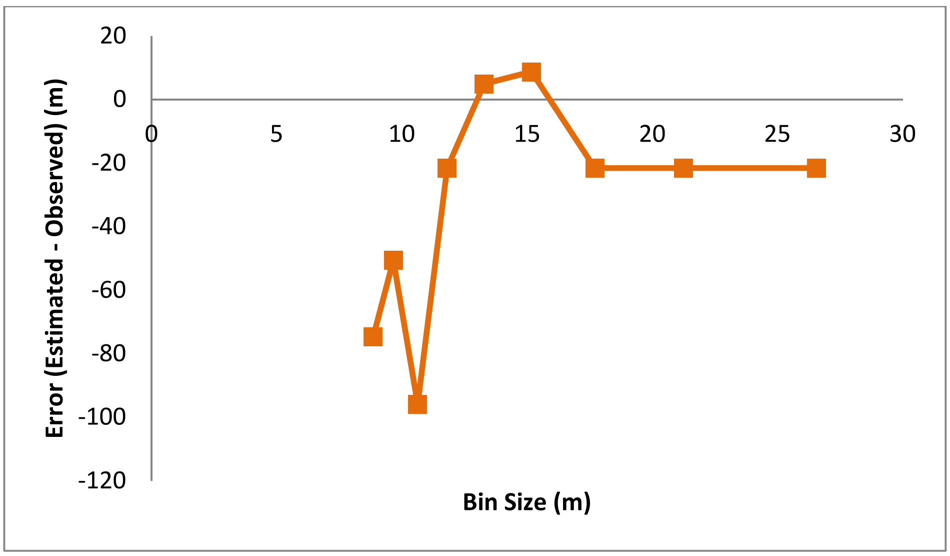


Figure 30. Error versus size of bins (parameter *k*)

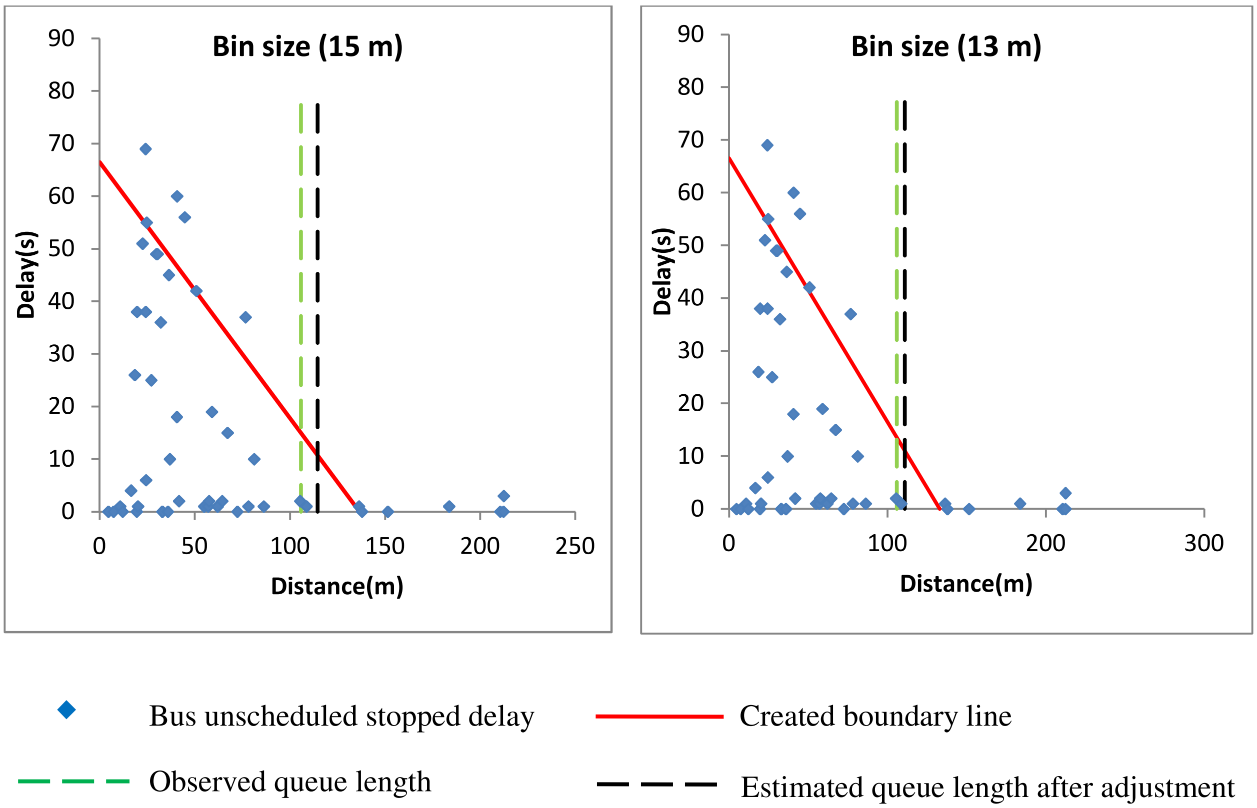
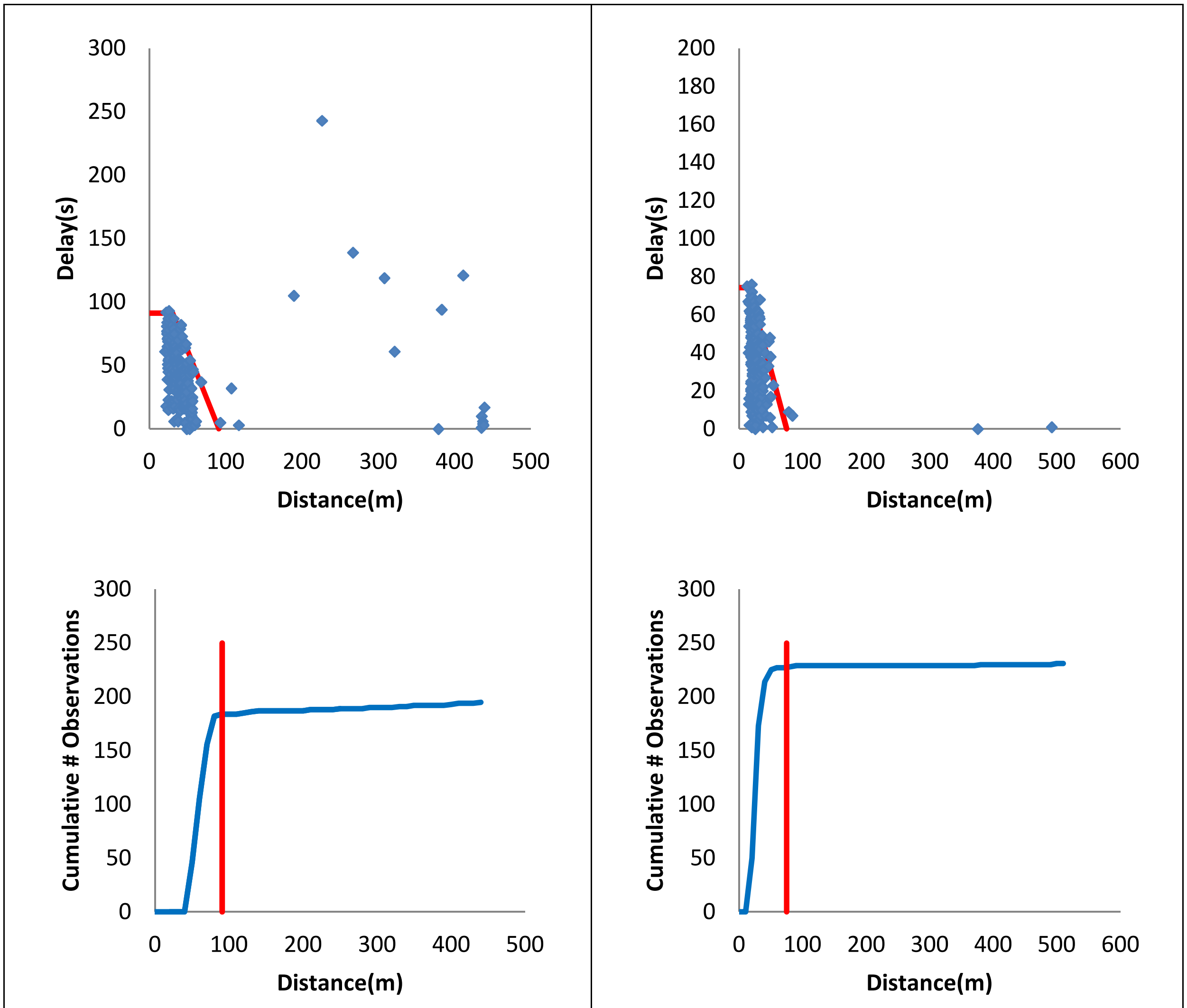


Figure 31. Boundary created by proposed method

The validity of using a bin size of 15m for other route segments was examined by applying the proposed methodology to a set of AVL/APC data for the PM peak period (4:30 – 6 PM) of weekdays for the period of Sept 6, 2011 through Dec. 23, 2011 on two other route segments. Except for 15m bin size, other input parameters are the same as the ones in Table 15.

The results of the application are given in Figure 32. We do not have independently observed field data (e.g. queue length and stopped delay data) for these segments over the analysis period and therefore it is not possible to objectively quantify the error. However, from the results we can observe that the created boundaries and cumulative observations graph are consistent with the patterns that are expected on the basis of theoretical foundations as described in Chapter 3.

We view this as confirmation that the proposed method along with the suggested parameter values, are applicable.



(a) Homer Waston Blvd at Manitou Drive (Route 10, "UP" direction given by GRT)

(b) Erb Street at Fisher Hallman Road (Route 201, "UP" direction given by GRT)

Figure 32. Boundary lines for two signalized intersections using 15m bin size

4.3 Conclusions

The calibration and validation described in this chapter have shown the following:

1. The distances derived from the AVL/APC data show very strong correlation with the field observations.
2. The stopped delay measures (i.e. mean, std) generated by the proposed methodology can be adjusted to estimate total delay using Equation 27.
3. It is necessary to adjust the derived distances by a constant equal to the distance from the intersection centroid (as stored within the GIS database) and the stopline for the approach of interest.

4. The estimates of maximum queue length appear to be somewhat sensitive to the value of *k*. It is recommended that a value of 15m (or approximately 2 times the distance headway of a single PCU in a stopped queue) be used.

Chapter 5: Application

In this chapter, the proposed methodology is applied to a set of Grand River Transit (GRT) routes using four months of non-holiday weekday AVL/APC data (from September 06, 2011 to December 23, 2011). In this application, analysis is conducted of only the PM peak period (4:30 – 6 PM) . The AVL/APC data and the GIS data utilized by the methodology are described. The final output from the analysis is a prioritized list of signalized intersections traversed by the studied routes. The prioritization is carried out on the basis of the estimated stopped delay measurements (e.g. mean and standard deviation) and estimated maximum queue length.

5.1 Transit Routes in Region of Waterloo

Grand River Transit is the public transport operator for the Region of Waterloo, Ontario, Canada. It operates daily bus services on over 60 transit routes in the region, primarily in the cities of Kitchener, Waterloo, and Cambridge as shown in Figure 31. Buses serving these routes travel over 12 million kilometres per year on fixed route schedules.

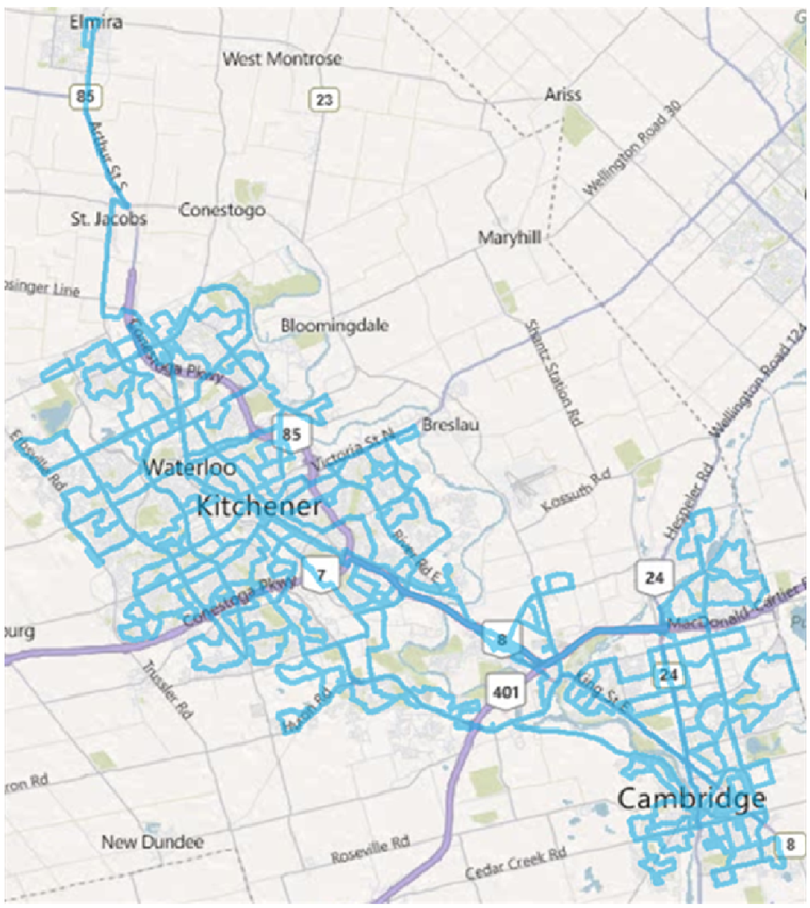


Figure 33. Grand River Transit service routes (blue lines)
(Background image source: Bing map)

5.2 Grand River Transit AVL/APC System

As described by Table 1 and Figure 7 in Chapter 2, the GRT AVL/APC system is a typical event-driven system. Bus events trigger the recording of data which are archived in a SQL database. In this database, there are two important tables. One is a trip-level table named *report_trip_start* and another one is named *report_stop*. The structure and fields descriptions of these two tables are provided in Figure 34 and Figure 35. These two tables contain part of the information required as input to the proposed methodology.

Fields	Type	Description
id	Number	Index (Primary Key)
course_id	Number	Reference to the course (Foreign Key for report_course_start.id)
op_day	Date	Operation date
line_no	Number	Line number (transit route number)
route_no	Number	Route number
course_no	Number	Course number
run_no	Number	Block index
vehicle_no	Number	Vehicle number
act_start_time	Number	Actual start time
act_start_time_hhmmss	String	Actual start time (as string)
actual_end_time	Number	Actual start time at the final recorded stop of trip (seconds past midnight)
actual_end_time_hhmmss	String	Actual start time at the final recorded stop of trip (as string)
sched_start_time	Number	Scheduled start time (seconds past midnight)
sched_start_time_hhmmss	String	Scheduled start time (as string)
sched_end_time	Number	Scheduled start time at the final recorded stop of trip (seconds past midnight)
sched_end_time_hhmmss	String	Scheduled start time at the final recorded stop of trip (as string)
route_direction	String	Route direction – no validation check
trip_no	Number	Trip number – no validation check
trip_id	Number	Reference to the ID in report_definition_trip
trip_type	Number	Trip type – no validation check 0 = Service Journey 1 = Unspecified Dead Run 2 = Outgoing Dead Run 3 = Interlink (Dead Run) 4 = Incoming Dead Run
destination_no	Number	Destination number – not utilized
destination_name	String	Destination name – not utilized
stopsequence	String	Stop sequence (lists the stop numbers on the trip)
odometer	Number	Odometer (m)
passenger_data	Number	Status of passenger counters 1 = At least one observation recorded
quality	Number	Percentage of scheduled stops versus actual stops recorded
pattern_completeness	Number	Same as quality field
data_source	Number	Code indicating data source

Figure 34. Fields in the *report_trip_start* (Source: Mandelzys, M., 2011)

Table *report_trip_start* stores information of bus trips. This information mainly consists of trip time stamp and identification characteristics. Time stamp refers to operation date, trip actual start time, trip actual end time, trip scheduled start time and trip scheduled end time. Identification characteristics refer to transit route number, route direction, trip type and so on.

Fields	Type	Description
id	Number	Index (Primary Key)
trip_id	Number	Reference to the trip (Foreign Key for report_trip_start.id)
op_day	Date	Operation day
vehicle_no	Number	Vehicle number
stop_no	Number	Stop number
stop_lname	String	Stop long name
stop_sname	String	Stop short name
stop_pos	Number	Stop position (i.e. nearside, farside, etc.) – not utilized
stop_type	Number	Stop type 0 = Stop with schedule time 2 = Stop with doors 3 = Stop without doors 4 = Drive through with schedule time 5 = Stop without schedule time 6 = Drive through without schedule time
prev_sched_stop_id	Number	Reference to the id of the previous record
stop_idx	Number	Index of stop on the pattern (report_definition_route)
sched_arr_time	Number	Scheduled arrival time (seconds past midnight)
sched_arr_time_hhmmss	String	Scheduled arrival time (as string)
sched_dep_time	Number	Scheduled departure time (seconds past midnight)
sched_dep_time_hhmmss	String	Scheduled departure time (as string)
act_arr_time	Number	Actual arrival time (seconds past midnight)
act_arr_time_hhmmss	String	Actual arrival time (as string)
act_dep_time	Number	Actual departure time (seconds past midnight)
act_dep_time_hhmmss	String	Actual departure time (as string)
odometer	Number	Odometer (m)
boarding	Number	Number of passengers boarding
alighting	Number	Number of passengers alighting
load	Number	Load (number of passengers)
e_boarding	Number	Boardings from extra stops
e_alighting	Number	Alightings from extra stops
e_load	Number	Load from extra stops
longitude	Number	Longitude GPS (WGS 84)
latitude	Number	Latitude GPS (WGS 84)
positioning_method	Number	Positioning method of the vehicle 0 = Real position 1 = Plan position

Figure 35. Fields in the *report_stop* (Source: Mandelzys, M., 2011)

Table *report_stop* mainly contains information of every bus event. This information also includes bus event time stamp and identification characteristics. **id** in *report_trip_start* is linked to **trip_id** in *report_stop* so as to find out which bus event belongs to which trip as well as to combine information from these two tables together.

Based on these descriptions above, questions about information required in proposed methodology can be sequentially answered by GRT AVL/APC data:

- **Q. How is an unscheduled stop archived in the GRT AVL/APC system?**
  A. An event which is recorded as stop_type = 3 in *report_stop* table is an unscheduled stop.

- **Q. Where did a stop event occur?**
  A. The location is each stop event is recorded in terms of the longitude and latitude as obtained from the GPS unit on the bus.

- **Q. What is the magnitude of the unscheduled stop delay?**
  A. Delay is dwell time of unscheduled stop obtained by *act_dep_time* minus *act_arr_time*.

- **Q. Which route and direction does it belong to?**
  A. After linking id in *report_trip_start* to trip_id in *report_stop*, *line_no* and *route_direction* information can be tagged onto bus event.

However, there is another part of information which can't be directly obtained using AVL/APC data only. So, the last question is:

- **Q. How is the location of an unscheduled stop event represented in terms of distance to the downstream stop line?**

To answer this question, another set of data, namely road network, bus route and signalized intersection location information, must be used. These data are explained in detail in the following sections.

5.3 Transit Route and Signalized Intersection GIS Data

AVL/APC data are not sufficient to obtain all information for implementing the proposed methodology. It also requires bus route and signalized intersection information to obtain bus route segment so that delay and distance relationship within this segment can be extracted. For bus route and signalized intersection information, geographical data in terms of bus routes layer and signalized intersections layer (Figure 36) are available to be utilized in this research. In Figure 36, the blue polyline represents all transit routes/directions and red points represent signalized intersections.

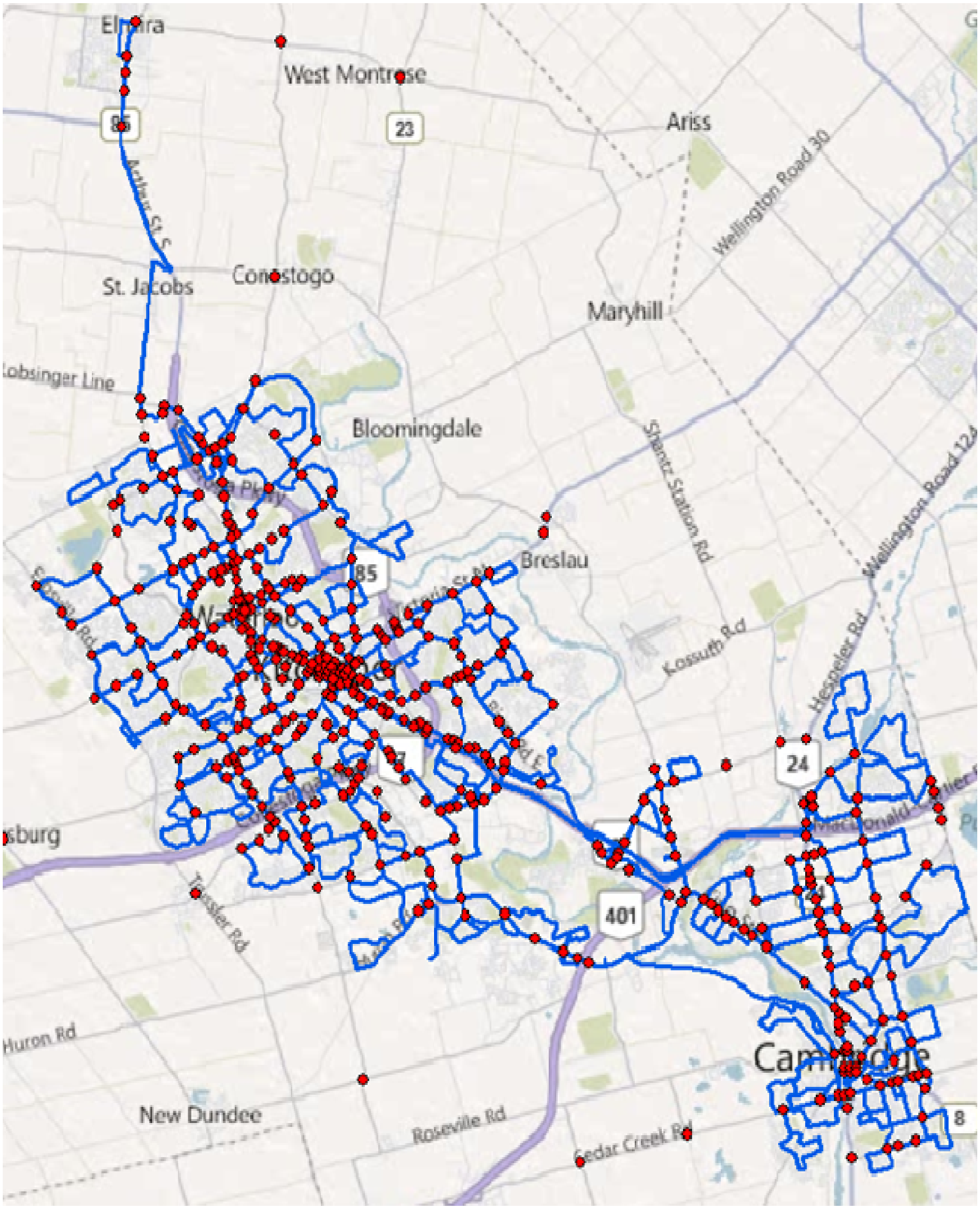


Figure 36. Transit routes and signal intersection layers in the Region of Waterloo (Background image source: Bing map)

Attribute table of blue polyline layer contains every single route/direction operated by GRT. Descriptions of major fields of this attribute table are provided in Table 17.

Table 17. Description of fields in the transit routes layer attribute table

Fields	Description
FID	primary key
ROUTE	transit route number (refer to Figure 33)
FULL_NAME	transit route name
Direction	transit route direction as given by GRT
Length	length for certain route/direction
CITY	city where the route/direction is operated
COMMENT	special notes for route/direction if it is applicable

Each row of this attribute table represents a certain route and direction. Figure 37 shows an example of this attribute table. For instance, for **FID** 37, it represents Route 10 and "up" direction. The length of this route/direction is 8.576 km.

FID	ROUTE	FULL_NAME	DIRECTION	LENGTH	CITY	COMMENT
37	10	Conestoga College	up	8.576	Kitchener	
38	10	Conestoga College	down	8.69	Kitchener	
39	11	Country Hills	IB	9.721	Kitchener	
40	11	Country Hills	OB	9.037	Kitchener	
41	110	Conestoga College Express	Down	8.189	Kitchener	stop at Pioneer plaza added se
42	110	Conestoga College Express	Up	8.328	Kitchener	stop at Pioneer plaza added se
43	116	Conestoga College Express	Dn	8.527	Kitchener	starts sep 2 2008
44	116	Conestoga College Express	Up	8.72	Kitchener	starts sep 2 2008
45	13	Laurelwood	EB	6.206	Waterloo	Sep 2007
46	13	Laurelwood	WB	4.187	Waterloo	Sep 2007

Figure 37. A screen shot of transit routes layer attribute table

The attribute table of red points layer contains information of every signalized intersection in Region of Waterloo. Descriptions of major fields of this attribute table are provided in Table 18.

Table 18. Description of fields in the signalized intersection layer attribute table

Fields	Description
FID	primary key
INT_NUM	intersection number given by GRT
MUNICIPALI	city where the intersection is located
LOCATION	intersection name

Each row of this attribute table represents a signalized intersection. Figure 38 shows an example of this attribute table. For instance, for **FID** 0, it represents intersection Erbsville at Columbia in the City of Waterloo.

FID	INT_NUM	MUNICIPALI	LOCATION
0	626	Waterloo	ERBSVILLE_AT_Columbia
1	41	Waterloo	WESTMOUNT_AT_Westcourt_Father_David Bauer
2	53	Waterloo	WEBER_AT_Marshall
3	20	Waterloo	COLUMBIA_AT_Philip
4	543	Waterloo	UNIVERSITY_AT_Albert
5	542	Waterloo	UNIVERSITY_AT_Phillip
6	622	Waterloo	ERB_AT_PEPPLER
7	54	Woolwich	WEBER_AT_Lincoln
8	541	Kitchener	UNIVERSITY_AT_Hazel
9	545	Waterloo	UNIVERSITY_AT_King
10	544	Waterloo	UNIVERSITY_AT_Regina
11	62	Waterloo	BRIDGEPORT_AT_Regina
12	264	Waterloo	BEARINGER_AT_PARKSIDE
13	502	Waterloo	KING_AT_Northfield
14	504	Waterloo	NORTHFIELD_AT_Parkside

Figure 38. A screen shot of signalized intersection layer attribute table

These GIS data provide the spatial reference information for the bus unscheduled stopped delay data. Using geographic information system (GIS) software and appropriate data processing strategy, delay and distance relationship can be extracted. A strategy to obtain this relationship is presented in the following section.

5.4 Sample of Processing Bus Route Segment and Obtaining Delay vs. Distance

Given the information described in the previous sections, bus unscheduled stopped delay and the distance from the stop location to the downstream signalized intersection can be obtained. An example is presented in the following section to explain the process of data extraction.

As described in the previous section, every route/direction is an attribute of the transit route layer. Each attribute is able to be separately used as a single layer. Consequently, integrating with signal intersection location, each route/direction can be segmented to create a bus route segment. To explain how the route/direction is segmented, a section of Route 200 (*iXpress*) with downward direction is used as an example and is shown in Figure 39. This section is segmented into seven bus route segments on the basis of definition of route segment in proposed methodology.

Figure 39. An example of segmentation (Background image source: Bing Map)

After obtaining bus route segments for a certain bus route/direction, it is required to identify those unscheduled stopped delays on this route/direction that were recorded to occur (spatially) within each segment. To do this, the AVL/APC longitude/latitude data (refer to Figure 36) of the bus unscheduled stopped delay are utilized. For a certain route and direction, bus unscheduled stopped delay can be exported as a point layer represented by yellow points in Figure 40. In this case, the point layer represent all bus unscheduled stopped delay occurrences along Route 200 (*iXpress*) with downward direction during the analysis period. Since the bus route segment is represented by a polyline layer, a spatial buffer is created to consider location proximity to identify occurrences of bus unscheduled stops as shown by blue rectangle area in Figure 40. Consequently, based on spatial relationship, the occurrence of bus unscheduled stopped delays within the buffer created for each segment is identified. Figure 40 shows an example of **Segment 1** as shown in Figure 39. The downstream intersection of this segment is University Avenue at Albert Street which is represented by red point A in Figure 40. Then with this given downstream signalized intersection information, the distance from these yellow unscheduled stopped delay points to red point A is calculated using the embedded tool in ArcGIS desktop.

This process is carried out for all segments on all routes and directions of interest. As a result, for every bus route segment, delay and distance matrix is obtained. After this step is completed, the proposed methodology is ready to be applied.

Figure 40. An example of bus route segment buffer and unscheduled stops within buffer (Background image source: Bing Map)

5.5 Study Route and Sample AVL/APC Data

In this thesis, 14 routes including Route 1, 9, 10, 11, 12, 13, 15, 23, 29, 200 (*iXpress*), 201(*iXpress*), 51, 52 and 53 are chosen as study routes as shown in Figure 39. During peak hours, time headway in *iXpress* routes is 10 minutes while others are varied[1]. Alignment of each route is provided in Appendix G. The reason to select these routes for application is that these routes have relatively high ridership and are therefore of interest to the local transit agency.

[1] For more information about bus schedule of these routes, please visit www.grt.ca.

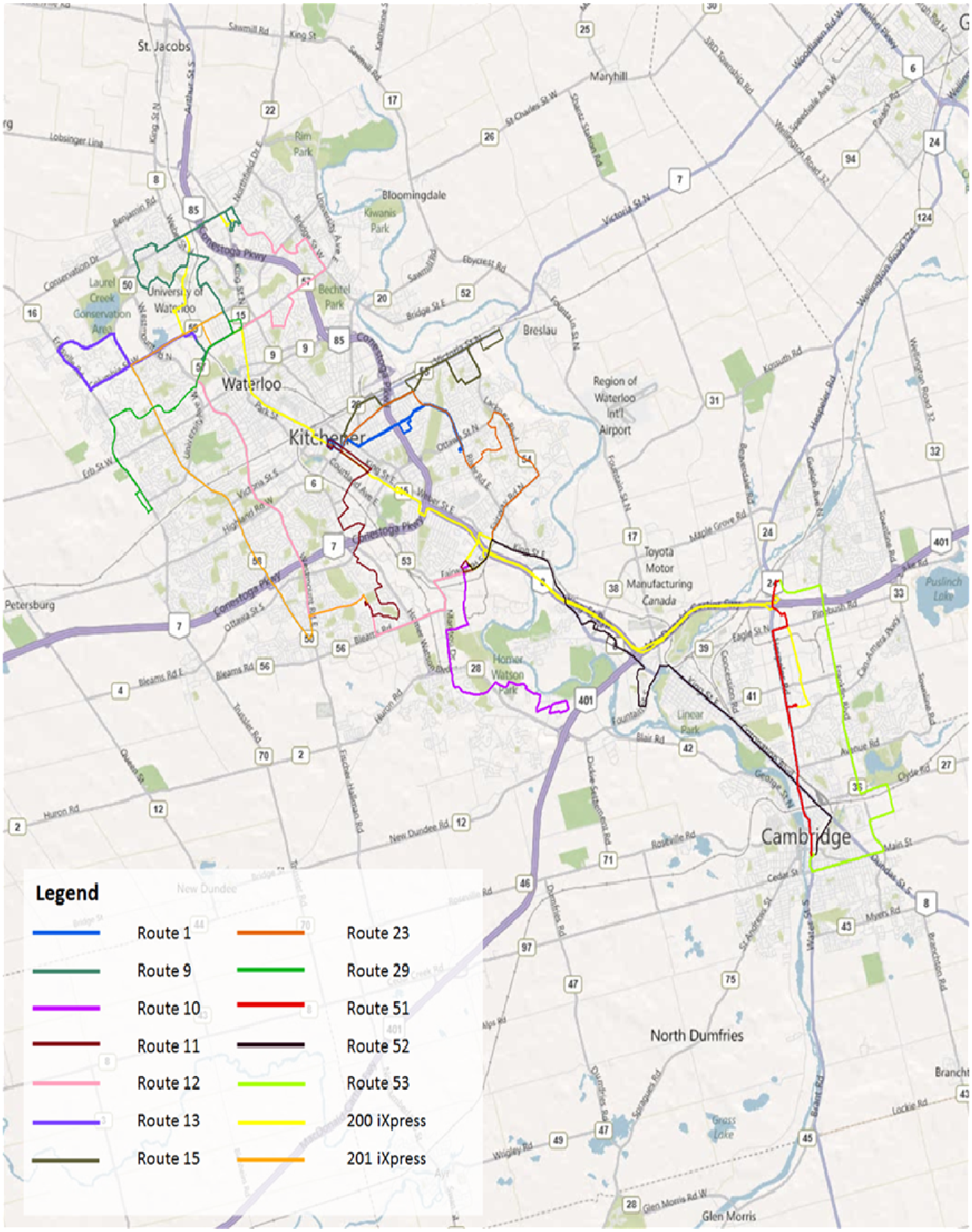


Figure 41. Study Routes (Background image source: Bing Map)

According to information from the local transit agency, delay at signalized intersection is generally more significant during the PM peak hour (4:30 PM - 6:00PM). Consequently, AVL/APC data of the 14 selected routes were extracted during the PM peak period over the period from September 06, 2011 to December 23, 2011. In this application, only service trips on non-holiday weekdays are considered.

On the basis of the definition of stop type for GRT AVL/APC system (refer to Table 1), if a bus unscheduled stop occurs at a near side transit stop, it will be recognized as a scheduled stop. This will result in an under-estimation of transit vehicle delays. Consequently, only segments with mid-lock transit stop or without any transit stop are chosen for application.

The proposed method was applied to 480 route segments.

Input parameters used within the proposed method are as shown in Table 19.

Table 19. Parameter values used for application to GRT routes

Parameters	Value
N_{min}	5
P_{obs}	5%
P_{delay}	99%
X_{max}	500 metres
l	15 metres

Results and discussions are provided in the next section.

5.6 Results and Discussions

The proposed method provided estimates of the following key measures:

1. Mean stopped delay

For a certain intersection approach, this mean delay is calculated by summation of identified Category 0 unscheduled stopped delays over total number of service trips recorded during analysis period. Trips without identified Category 0 unscheduled stopped delays are considered to experience zero delay. This measurement provides average delay level for every single intersection approach.

2. Standard deviation of stopped delay

According to explanation of calculation of mean delay, this measure is straightforward to compute. Please note that, if a trip experienced two or more identified Category 0 unscheduled stopped delays, these delays are aggregated and considered as one single delay for calculating standard deviation. This measurement is able to explain how the delay varies for a certain intersection approach.

3. 90th percentile of stopped delay

This measure is obtained on the basis of identified Category 0 unscheduled stopped delays from trips and zero delay from trips without Category 0 delay. This statistic gives user a sense that the cumulative distribution of magnitude of delay.

4. Proportion of service trips that were required to stop at the signalized intersection

This is calculated by number of trips with identified Category 0 unscheduled stopped delays over total number of service trips recorded during analysis period. This measurement provides the probability that a bus will experience signal delay for a certain intersection approach.

5. Maximum extent of the queue $\boldsymbol{X_{P2}}$

This is directly estimated by method described in Chapter 3. In conjunction with other measurements, it can provide assistance for choosing transit signal priority measures (i.e. queue jump lanes).

6. Saturation degree Indicator $\boldsymbol{X_{P1}}$

This is directly estimated by method described in Chapter 3. This indicates the degree of saturation for a certain intersection approach.

7. Maximum delay $\boldsymbol{d_{max}}$

This is directly estimated by method described in Chapter 3. This indicates the maximum delay which can be experienced by per stop for a certain intersection approach. This also is interpreted as red time.

To obtain a ranked list of intersection, it is not very reasonable to only rely on one measure. For example, if we only utilize mean delay as an index and obtain two intersections with same mean delay, it is necessary to examine other measurements to determine which intersection has more serious problem. Consequently, it is necessary to consider comprehensively these measurements.

An approach having a high proportion of trips having to stop, is also likely to have a high mean delay and a high 90th percentile of delay. However, the queue length in a given cycle is a function of v/c but also on cycle length, since the longer the cycle length the longer the queue will be. But for a given v/c ratio, the proportion of vehicles having to stop will be the same regardless of the length of the queue. Considering these, mean delay, 90th percentile of delay and proportion of trips with delay are important for identifying intersections at which reducing signal delay could be beneficial. It is proposed to calculate an index value as the average of the standardized values of these three measures as follows:

$$I = 1/3(P) + 1/3(M_d) + 1/3(N_d) \tag{28}$$

Where:

I = index value ($0 < I \leq 100$) higher value indicates higher priority

p = proportion of trips having to stop ($0 \leq p \leq 100\%$)

p_{min} = minimum value of p across all intersection approaches

p_{max} = maximum value of p across all intersection approaches

P = normalized proportion of trips having to stop, which is equal to $(p - p_{min})/(p_{max} - p_{min})$

m = mean stopped delay (seconds)

m_{min} = minimum value of m across all intersection approaches

m_{max} = maximum value of m across all intersection approaches

M_d = normalized mean stopped delay, which is equal to $(m - m_{min})/(m_{max} - m_{min})$

n = 90th percentile of mean stopped delay (seconds)

n_{min} = minimum value of n across all intersection approaches

n_{max} = maximum value of n across all intersection approaches

N_d = normalized 90th percentile of stopped delay, which is equal to $(n - n_{min})/(n_{max} - n_{min})$

According to Equation 28, the list of top 15 ranked intersection approaches in study routes are shown in Table 20. The complete list and related delay measure is provided in Appendix H.

Table 20. Top 15 intersections for transit priority treatments based on proposed index

			Stats based on all service trips							Based only on stopped delays					
Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	Coefficient of Variance (COV)	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1} (m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Dn	HESPELER @Eagle/Pinebush	39.0	43.5	1.1	101	58%	42%	446	102	44	130.0	280	87%	1
11	IB	OTTAWA @Homer Watson	39.1	24.0	0.6	64	85%	15%	252	189	117	88.0	268	85%	2
10	up	HOMER WATSON @Manitou&Doon Village	34.4	25.2	0.7	69.4	81%	19%	217	91	30	91.3	201	81%	3
15	ib	VICTORIA @Natchez	31.7	28.1	0.9	72.7	77%	23%	214	76	15	100.1	234	79%	4
53	IB	FRANKLIN @Savage	31.1	27.4	0.9	71	79%	21%	221	76	30	95.1	310	78%	5
9	DN	NORTHFIELD @Kraus	29.6	27.6	0.9	69.4	75%	25%	164	76	15	111.0	190	75%	6
23	Up	FAIRWAY @Fairview Park Mall	30.8	30.6	1.0	75	65%	35%	222	131	58	98.8	255	74%	7
10	down	FAIRWAY @Wilson	32.1	28.1	0.9	64.7	71%	29%	214	120	30	84.4	258	74%	8
201	dn	FISCHER HALLMAN @Greenbrook/Hwy 7&8	33.4	36.2	1.1	82	52%	48%	319	152	91	115.7	445	74%	9
10	down	HOMER WATSON @Manitou&Doon Village	28.6	27.3	1.0	68	73%	27%	214	197	61	76.6	264	73%	10
9	UP	NORTHFIELD @Skylark	31.1	27.5	0.9	65	69%	31%	231	76	15	89.0	189	73%	11
29	EB	UNIVERSITY @Keatsway	27.5	26.2	1.0	66.8	71%	29%	263	106	30	91.4	207	71%	12
10	down	HOMER WATSON@Pioneer	25.6	22.3	0.9	58	80%	20%	214	91	30	79.3	179	70%	13
13	EB	WESTMOUNT @Columbia	26.8	21.4	0.8	56.6	74%	26%	235	91	45	69.4	185	68%	14
200	up	PINEBUSH @Conestoga	26.0	30.9	1.2	77	55%	45%	600	91	30	114.0	463	67%	15

From Table 20, it can be seen that Route 11/IB approach at *OTTAWA@Homer Watson* experiences the largest mean delay BUT it is ranked at 2nd position as a result of a smaller 90th percentile delay compared with the counterpart for Route 51/Dn approach at *HESPELER@Eagle/Pinebush*. Although the Route 51/Dn approach at *HESPELER@Eagle/Pinebush* has a smaller proportion of trips that experience signal delay, on average the buses on this route/approach experience larger delays. This implies that there is also a large variation in signal delays experienced by different bus trips and this is reflected by the coefficient of variation (standard deviation divided by the mean) which is much larger than for the second ranked route/approach.

The proposed index which combines mean delay, 90th percentile of delay and proportion of trips experiencing signal delay, can be used to prioritize intersections for priority treatment. In this example application, each of these three measures has been equally weighted. The choice of weightings is subjective as there is no theoretical reason to justify this weighting scheme, or any other scheme. Nevertheless, the proposed approach permits the use of different weightings if a transit agency wished to do so.

In addition to the prioritization index, the other measurements of output (i.e. queue length and maximum delay) can provide assistance in selecting between priority treatments. Note that when using the estimated maximum queue length, the correction factor (distance between intersection centroid and stopline) should be considered. And also, note that the delay measures only represent a portion of total delay. To use them to predict total delay, Equation 27 can be utilized.

Using the GIS intersection layer, this intersection numerical list also can be plotted in GIS environment so as to provide visual aid to identify these locations as shown by Figure 42. The size of the circle represents the magnitude of index. In this way, it is easy to target the hot spot intersection with large size circle.

Figure 42. Top 15 intersection approach locations

Also, after identifying these most problematic intersection approaches we can make use of GIS to examine how bus stopped delay distributes spatially so as to provide more assistance to investigate these intersection approaches. Two examples are shown in Table 21.

Table 21. Top 2 intersection approach stopped delay spatial distribution pattern in GIS

Rank	Spatial distribution of Stopped Delays
1	
2	

Signalized intersection — Identified Category 0 delay (signal delay)

Identified other category delay — Bus segment buffer

Bus travel direction

Chapter 6: Conclusions and Recommendations

In this thesis, a methodology for estimating signalized intersection delay using AVL/APC data is proposed. The method is based on sound traffic engineering principles and is consistent with queuing and shockwave theories.

The method can be applied by transit agencies which have archived AVL/APC data that captures "events", including unscheduled stopped delays. The method requires only the following data:

1. Archived AVL/APC data
2. Locations of signalized intersections and transit routes (accessible within a GIS database).

The proposed method can provide estimates of (1) the maximum extent of the queue; and (2) measures of the distribution of stopped delays experienced by transit vehicles (e.g. mean, standard deviation, 90^{th} percentile, etc.) caused by the downstream traffic signal. These measures can be produced separately for different analysis periods (e.g. different times of the day; days of the week; and time of the year) and can be compiled separately for different transit routes.

The proposed delay measures index integrate mean delay, 90th percentile of means delay and proportion of trips into one single indicator which can be utilized to identify and prioritize signalized intersections as candidates for transit signal priority measures. Other measurements (e.g. queue length and maximum delay) can provide assistance when considering different types of transit signal priority measures (e.g. queue jump lane).

The comparison of the results from the proposed method to field data shows that the proposed method provides estimates of the maximum extent of the queue are sufficiently accurate when considering correction factor (distance between intersection gps location and real stopline). It is recommended that when maximum queue length is considered to be utilized for a certain intersection approach, this length should be adjusted by correction factor. This value can be easily measured by using Google satellite image and intersection location data.

The comparison between total delay and transit vehicle stopped delays indicates that stopped delays estimated from AVL/APC data represent, on average, 62.5% of total delay.

It is recognized that the evaluation of the proposed method is based on a relatively small sample of field data and ideally the method should be validate against a larger set of data for a number of different route segments. However, collecting and processing field data to obtain the maximum extent of the queue on a signalized intersection approach is a resource intensive process. Furthermore, though the use of video cameras to collect the field data and permit post-processing has many advantages, the need to position the cameras at a sufficient height to provide an appropriate field of view significantly limits the number of locations at which field data can be collected.

The proposed method has been evaluated using transit route data in which no near-side stops existed. It is recognized that the application of the proposed method to intersections with near-side stops will result in an under-estimation of transit vehicle delays. The extent of this under-estimation should be quantified and efforts should be made to reduce this estimation error.

The proposed method suggests using an index to rank intersections. This index is calculated on the basis of standardized mean delay, 90th percentile of delay and proportion of trips with delay. These three measures are chosen relatively subjectively. More investigation should be conducted on other measures. For example, ridership (can be obtained from APC) affected by delays at intersections are valuable to assist to identify intersections which may need treatment. However, it should be careful to use this value since even ridership is very low at an intersection delay may still have some negative impacts on downstream bus stop (e.g. schedule adherence) which may cause anxiety of passengers waiting for bus.

The proposed method is applied using PM peak hour data recorded by AVL/APC system. However, due to data recovery rate and portion of buses equipped with AVL/APC, not every trip is recorded in the AVL/APC system. Although the total number of service trips in the output table can give some sense about sample size, influence of the records which are not stored on the delay measures should be investigated in the future.

The proposed method has potential ability to be implemented completely automatically. Current data processing method in this thesis involves part of manual work which limits application of size of route network. Although for 14 routes analysis is completed in an acceptable time period, optimization of automatic processing is recommended so as to make the proposed methodology suitable for larger networks.

Finally, it is recommended that Grand River Transit conduct a detailed analysis of the performance of the route/intersection approaches identified in Table 21 to determine if transit priority measures are warranted and which type of treatment is most suitable.

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Appendices

Appendix A. Observed number of vehicles and related queue length

Obs Date	Obs #	Number of Passenger Cars in Queue	Number of Heavy Vehicles (truck and bus) in Queue	Number of PCU in Queue	Observed Queue Length(meters)
2011/10/3	1	14	0	14	135
2011/10/3	2	15	0	15	137
2011/10/3	3	17	1	19.25	162
2011/10/3	4	16	0	16	138
2011/10/3	5	17	0	17	150
2011/10/3	6	16	0	16	144
2011/10/3	7	17	0	17	163
2011/10/3	8	19	0	19	158
2011/10/3	9	17	0	17	163
2011/10/4	10	18	0	18	162
2011/10/4	11	15	0	15	137
2011/10/4	12	17	0	17	160
2011/10/4	13	19	0	19	162
2011/10/5	14	18	0	18	158
2011/10/5	15	20	0	20	158
2011/10/5	16	19	0	19	158
2011/10/5	17	17	0	17	138
2011/10/5	18	20	0	20	158
2011/10/5	19	18	0	18	158
2011/10/5	20	17	0	17	157
2011/10/5	21	18	0	18	146
2011/10/5	22	18	0	18	157
2011/10/5	23	20	0	20	157
2011/10/5	24	18	0	18	158
2011/10/5	25	19	0	19	157
2011/10/5	26	18	0	18	158
2011/10/5	27	18	1	20.25	158
2011/10/5	28	19	0	19	158
2011/10/5	29	20	0	20	158
2011/10/5	30	19	0	19	158
2011/10/5	31	18	0	18	158
2011/10/5	32	19	0	19	158
2011/10/6	33	17	0	17	144
2011/10/6	34	15	1	17.25	131
2011/10/6	35	20	0	20	145
2011/10/6	36	15	2	19.5	144
2011/10/6	37	17	1	19.25	140
2011/10/6	38	20	0	20	146

Obs Date	Obs #	Number of Passenger Cars in Queue	Number of Heavy Vehicles (truck and bus) in Queue	Number of PCU in Queue	Observed Queue Length(meters)
2011/10/6	39	20	0	20	146
2011/10/6	40	20	0	20	153
2011/10/6	41	19	1	21.25	155
2011/10/6	42	20	0	20	146
2011/10/6	43	18	2	22.5	145
2011/10/6	44	19	0	19	140
2011/10/6	45	18	0	18	144
2011/10/6	46	19	0	19	146
2011/10/6	47	21	0	21	150
2011/10/6	48	20	0	20	148
2011/10/6	49	19	0	19	151
2011/10/6	50	20	0	20	155
2011/10/6	51	21	0	21	155
2011/10/6	52	21	0	21	155
2011/10/6	53	21	0	21	155
2011/10/6	54	21	0	21	155
2011/10/6	55	20	0	20	155
2011/10/6	56	20	0	20	152
2011/10/6	57	19	0	19	154
2011/10/6	58	20	0	20	153
2011/10/6	59	19	0	19	150
2011/10/6	60	20	0	20	152
2011/10/6	61	20	0	20	154
2011/10/6	62	21	0	21	155
2011/10/6	63	20	0	20	150
2011/10/6	64	19	0	19	150
2011/10/6	65	21	0	21	155
2011/10/6	66	17	0	17	133
2011/10/6	67	18	0	18	150
2011/10/6	68	20	0	20	155
2011/10/6	69	21	0	21	146
2011/10/6	70	18	1	20.25	144
2011/10/6	71	16	2	20.5	152
2011/10/6	72	19	1	21.25	149
2011/10/6	73	20	1	22.25	155
2011/10/6	74	20	0	20	150
2011/10/6	75	17	2	21.5	150
2011/10/6	76	20	1	22.25	155
2011/10/6	77	18	1	20.25	150

Obs Date	Obs #	Number of Passenger Cars in Queue	Number of Heavy Vehicles (truck and bus) in Queue	Number of PCU in Queue	Observed Queue Length(meters)
2011/10/6	78	20	0	20	151
2011/10/6	79	20	0	20	154
2011/10/6	80	16	3	22.75	152
2011/10/6	81	16	2	20.5	147
2011/10/6	82	18	2	22.5	154
2011/10/6	83	18	2	22.5	152
2011/10/6	84	15	3	21.75	150
2011/10/6	85	15	3	21.75	152
2011/10/6	86	15	3	21.75	144
2011/10/6	87	16	2	20.5	152
2011/10/7	88	25	0	25	190
2011/10/7	89	18	0	18	135
2011/10/7	90	19	1	21.25	163
2011/10/7	91	17	0	17	135
2011/10/11	92	21	0	21	163
2011/10/11	93	18	0	18	140
2011/10/11	94	19	0	19	160
2011/10/11	95	18	0	18	140
2011/10/11	96	19	0	19	152
2011/10/11	97	21	0	21	160
2011/10/11	98	19	0	19	160
2011/10/11	99	21	0	21	160
2011/10/13	100	20	0	20	155
2011/10/13	101	19	0	19	154
2011/10/13	102	16	0	16	135
2011/10/13	103	17	0	17	140
2011/10/13	104	16	0	16	136
2011/10/13	105	16	0	16	140
2011/10/13	106	20	0	20	150
2011/10/13	107	18	0	18	144
2011/10/13	108	21	0	21	158
2011/10/13	109	21	0	21	155
2011/10/13	110	19	0	19	155
2011/10/13	111	20	0	20	150
2011/10/13	112	20	0	20	160
2011/10/14	113	17	0	17	163
2011/10/14	114	18	0	18	163
2011/10/14	115	16	0	16	163
2011/10/14	116	17	0	17	163

Obs Date	Obs #	Number of Passenger Cars in Queue	Number of Heavy Vehicles (truck and bus) in Queue	Number of PCU in Queue	Observed Queue Length(meters)
2011/10/14	117	18	0	18	163
2011/10/14	118	19	0	19	163
2011/10/14	119	14	0	14	140
2011/10/14	120	17	0	17	163
2011/10/14	121	18	0	18	163
2011/10/14	122	17	1	19.25	163
2011/10/14	123	17	1	19.25	163
2011/10/14	124	19	0	19	163
2011/10/14	125	20	0	20	163
2011/10/14	126	18	0	18	163
2011/10/14	127	19	1	21.25	163
2011/10/14	128	15	1	17.25	163
2011/10/14	129	20	1	22.25	162
2011/10/14	130	16	1	18.25	162
2011/10/14	131	16	2	20.5	162
2011/10/14	132	16	0	16	163
2011/10/14	133	18	0	18	163
2011/10/14	134	17	0	17	163
2011/10/17	135	19	0	19	163
2011/10/17	136	17	0	17	163
2011/10/17	137	15	0	15	160
2011/10/17	138	17	0	17	158
2011/10/17	139	19	0	19	162
2011/10/17	140	15	0	15	140
2011/10/17	141	18	0	18	163
2011/10/17	142	16	0	16	150
2011/10/17	143	11	1	13.25	138

Appendix B. Field queue observation

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/3	1	7	0		7	55.9
2011/10/3	2	8	0		8	63.9
2011/10/3	3	2	1		4.25	34.0
2011/10/3	4	3	0		3	24.0
2011/10/3	5	1	0		1	8.0
2011/10/3	6	5	0		5	39.9
2011/10/3	7	1	0		1	8.0
2011/10/3	8	2	0		2	16.0
2011/10/3	9	2	0		2	16.0
2011/10/3	10	4	1		6.25	49.9
2011/10/3	11	2	0		2	16.0
2011/10/3	12	4	0		4	32.0
2011/10/3	13	4	0		4	32.0
2011/10/3	14	1	1		3.25	26.0
2011/10/3	15	2	0		2	16.0
2011/10/3	16	5	0		5	39.9
2011/10/3	17	11	0		11	87.9
2011/10/3	18	3	0		3	24.0
2011/10/3	19	4	0		4	32.0
2011/10/3	20	2	0		2	16.0
2011/10/3	21	1	0		1	8.0
2011/10/3	22	2	0		2	16.0
2011/10/3	23	2	0		2	16.0
2011/10/3	24	10	0		10	79.9
2011/10/3	25	5	1		7.25	57.9
2011/10/3	26	6	1		8.25	65.9
2011/10/3	27	6	0		6	47.9
2011/10/3	28	4	0		4	32.0
2011/10/3	29	8	0		8	63.9
2011/10/3	30	5	0		5	39.9
2011/10/3	31	8	0		8	63.9
2011/10/3	32	4	0		4	32.0
2011/10/3	33	7	1		9.25	73.9
2011/10/3	34	11	0		11	87.9
2011/10/3	35	9	0		9	71.9
2011/10/3	36	8	1		10.25	81.9
2011/10/3	37	8	0		8	63.9
2011/10/3	38	9	0		9	71.9
2011/10/4	39	9	0		9	71.9

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/4	40	5	0		5	39.9
2011/10/4	41	3	0		3	24.0
2011/10/4	42	6	0		6	47.9
2011/10/4	43	3	0		3	24.0
2011/10/4	44	2	0		2	16.0
2011/10/4	45	7	3		13.75	109.8
2011/10/4	46	5	0		5	39.9
2011/10/4	47	6	1		8.25	65.9
2011/10/4	48	2	1		4.25	34.0
2011/10/4	49	1	0		1	8.0
2011/10/4	50	4	0		4	32.0
2011/10/4	51	4	0		4	32.0
2011/10/4	52	2	0		2	16.0
2011/10/4	53	3	0		3	24.0
2011/10/4	54	3	0		3	24.0
2011/10/4	55	2	0		2	16.0
2011/10/4	56	7	0		7	55.9
2011/10/4	57	3	0		3	24.0
2011/10/4	58	4	0		4	32.0
2011/10/4	59	4	0		4	32.0
2011/10/4	60	6	0		6	47.9
2011/10/7	61	1	0		1	8.0
2011/10/7	62	3	0		3	24.0
2011/10/7	63	4	0		4	32.0
2011/10/7	64	3	0		3	24.0
2011/10/7	65	5	0		5	39.9
2011/10/7	66	0	0		0	0.0
2011/10/7	67	4	0		4	32.0
2011/10/7	68	0	0		0	0.0
2011/10/7	69	4	0		4	32.0
2011/10/7	70	1	1		3.25	26.0
2011/10/7	71	5	0		5	39.9
2011/10/7	72	1	1		3.25	26.0
2011/10/7	73	3	0		3	24.0
2011/10/7	74	2	0		2	16.0
2011/10/7	75	3	0		3	24.0
2011/10/7	76	5	0		5	39.9
2011/10/7	77	20	1	163	22.25	163.0
2011/10/7	78	5	0		5	39.9

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/7	79	6	0		6	47.9
2011/10/7	80	0	0		0	0.0
2011/10/7	81	17	0	135	17	135.0
2011/10/7	82	3	0		3	24.0
2011/10/7	83	10	0		10	79.9
2011/10/7	84	3	0		3	24.0
2011/10/7	85	1	0		1	8.0
2011/10/7	86	5	1		7.25	57.9
2011/10/7	87	2	0		2	16.0
2011/10/7	88	3	0		3	24.0
2011/10/7	89	0	0		0	0.0
2011/10/7	90	3	0		3	24.0
2011/10/7	91	3	0		3	24.0
2011/10/7	92	9	0		9	71.9
2011/10/7	93	1	0		1	8.0
2011/10/7	94	1	0		1	8.0
2011/10/7	95	4	0		4	32.0
2011/10/7	96	10	0		10	79.9
2011/10/7	97	7	0		7	55.9
2011/10/7	98	1	0		1	8.0
2011/10/7	99	7	0		7	55.9
2011/10/7	100	7	1		9.25	73.9
2011/10/7	101	1	0		1	8.0
2011/10/7	102	0	0		0	0.0
2011/10/11	103	2	0		2	16.0
2011/10/11	104	1	1		3.25	26.0
2011/10/11	105	7	0		7	55.9
2011/10/11	106	4	0		4	32.0
2011/10/11	107	1	0		1	8.0
2011/10/11	108	6	0		6	47.9
2011/10/11	109	6	1		8.25	65.9
2011/10/11	110	5	0		5	39.9
2011/10/11	111	1	0		1	8.0
2011/10/11	112	0	0		0	0.0
2011/10/11	113	4	2		8.5	67.9
2011/10/11	114	4	0		4	32.0
2011/10/11	115	3	2		7.5	59.9
2011/10/11	116	3	0		3	24.0
2011/10/11	117	0	0		0	0.0

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/11	118	1	0		1	8.0
2011/10/11	119	1	0		1	8.0
2011/10/11	120	1	0		1	8.0
2011/10/11	121	10	0		10	79.9
2011/10/11	122	1	0		1	8.0
2011/10/11	123	3	0		3	24.0
2011/10/11	124	3	0		3	24.0
2011/10/11	125	2	1		4.25	34.0
2011/10/11	126	1	0		1	8.0
2011/10/11	127	7	1		9.25	73.9
2011/10/11	128	9	0		9	71.9
2011/10/11	129	6	0		6	47.9
2011/10/11	130	10	0		10	79.9
2011/10/11	131	8	0		8	63.9
2011/10/11	132	7	0		7	55.9
2011/10/11	133	8	1		10.25	81.9
2011/10/11	134	15	0		15	119.8
2011/10/11	135	11	1		13.25	105.9
2011/10/11	136	5	0		5	39.9
2011/10/11	137	5	1		7.25	57.9
2011/10/11	138	8	0		8	63.9
2011/10/11	139	1	0		1	8.0
2011/10/11	140	1	0		1	8.0
2011/10/11	141	6	0		6	47.9
2011/10/11	142	4	0		4	32.0
2011/10/11	143	7	0		7	55.9
2011/10/11	144	2	0		2	16.0
2011/10/11	145	1	0		1	8.0
2011/10/11	146	1	0		1	8.0
2011/10/11	147	5	0		5	39.9
2011/10/11	148	11	0		11	87.9
2011/10/13	149	3	0		3	24.0
2011/10/13	150	8	0		8	63.9
2011/10/13	151	4	0		4	32.0
2011/10/13	152	2	1		4.25	34.0
2011/10/13	153	11	1		13.25	105.9
2011/10/13	154	7	0		7	55.9
2011/10/13	155	4	0		4	32.0
2011/10/13	156	6	1		8.25	65.9

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/13	157	1	1		3.25	26.0
2011/10/13	158	8	1		10.25	81.9
2011/10/13	159	4	0		4	32.0
2011/10/13	160	4	0		4	32.0
2011/10/13	161	3	0		3	24.0
2011/10/13	162	6	1		8.25	65.9
2011/10/13	163	4	0		4	32.0
2011/10/13	164	12	0		12	95.9
2011/10/13	165	2	0		2	16.0
2011/10/13	166	3	1		5.25	41.9
2011/10/13	167	6	0		6	47.9
2011/10/13	168	6	0		6	47.9
2011/10/13	169	4	0		4	32.0
2011/10/13	170	2	0		2	16.0
2011/10/13	171	5	0		5	39.9
2011/10/13	172	1	0		1	8.0
2011/10/13	173	4	0		4	32.0
2011/10/13	174	6	0		6	47.9
2011/10/13	175	6	0		6	47.9
2011/10/13	176	4	0		4	32.0
2011/10/13	177	1	0		1	8.0
2011/10/13	178	2	0		2	16.0
2011/10/13	179	5	0		5	39.9
2011/10/13	180	0	1		2.25	18.0
2011/10/13	181	4	0		4	32.0
2011/10/13	182	10	1		12.25	97.9
2011/10/13	183	7	1		9.25	73.9
2011/10/13	184	3	1		5.25	41.9
2011/10/13	185	5	1		7.25	57.9
2011/10/13	186	3	0		3	24.0
2011/10/13	187	3	1		5.25	41.9
2011/10/13	188	12	0		12	95.9
2011/10/13	189	20	0	150	20	150.0
2011/10/13	190	20	0	160	20	160.0
2011/10/13	191	13	0		13	103.9
2011/10/13	192	2	0		2	16.0
2011/10/13	193	11	1		13.25	105.9
2011/10/13	194	3	1		5.25	41.9
2011/10/13	195	4	0		4	32.0

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/13	196	5	1		7.25	57.9
2011/10/13	197	1	0		1	8.0
2011/10/13	198	5	0		5	39.9
2011/10/14	199	1	0		1	8.0
2011/10/14	200	3	2		7.5	59.9
2011/10/14	201	6	0		6	47.9
2011/10/14	202	2	0		2	16.0
2011/10/14	203	9	0		9	71.9
2011/10/14	204	6	0		6	47.9
2011/10/14	205	3	0		3	24.0
2011/10/14	206	3	0		3	24.0
2011/10/14	207	7	0		7	55.9
2011/10/14	208	10	2		14.5	115.8
2011/10/14	209	12	1		14.25	113.8
2011/10/14	210	10	1		12.25	97.9
2011/10/14	211	8	0		8	63.9
2011/10/14	212	2	0		2	16.0
2011/10/14	213	5	0		5	39.9
2011/10/14	214	6	1		8.25	65.9
2011/10/17	215	3	0		3	24.0
2011/10/17	216	5	1		7.25	57.9
2011/10/17	217	10	0		10	79.9
2011/10/17	218	8	0		8	63.9
2011/10/17	219	7	0		7	55.9
2011/10/17	220	8	0		8	63.9
2011/10/17	221	7	0		7	55.9
2011/10/17	222	2	0		2	16.0
2011/10/17	223	6	1		8.25	65.9
2011/10/17	224	3	0		3	24.0
2011/10/17	225	2	0		2	16.0
2011/10/17	226	1	0		1	8.0
2011/10/17	227	5	0		5	39.9
2011/10/17	228	2	0		2	16.0
2011/10/17	229	4	0		4	32.0
2011/10/17	230	2	0		2	16.0
2011/10/17	231	1	0		1	8.0
2011/10/17	232	6	1		8.25	65.9
2011/10/17	233	8	0		8	63.9
2011/10/17	234	5	0		5	39.9

Obs Date	Obs #	Number of Passenger Cars	Number of Heavy Vehicles	Right lane queue tail measured by transparency	Number of PCU	Queue length (meters)
2011/10/17	235	7	0		7	55.9
2011/10/17	236	11	1	138	13.25	138.0
2011/10/17	237	12	1		14.25	113.8
2011/10/17	238	8	1		10.25	81.9
2011/10/17	239	2	0		2	16.0
2011/10/17	240	4	0		4	32.0
2011/10/17	241	4	1		6.25	49.9
2011/10/17	242	3	0		3	24.0
2011/10/17	243	8	0		8	63.9
2011/10/17	244	5	0		5	39.9
2011/10/17	245	4	0		4	32.0
2011/10/17	246	4	0		4	32.0
2011/10/17	247	7	0		7	55.9
2011/10/17	248	8	0		8	63.9
2011/10/17	249	10	2		14.5	115.8
2011/10/17	250	6	0		6	47.9
2011/10/17	251	8	1		10.25	81.9
2011/10/17	252	9	0		9	71.9
2011/10/17	253	6	0		6	47.9

Appendix C. Locations for observed unscheduled stopped stop delay events

Date	Route	Time	Number of vehicles in downstream of bus				Position measured by reference lines (metres)		PCU	Distance of bus to stopline (meters)
			Passenger cars		Heavy vehicles					
			Left lane	Right lane	Left lane	Right lane	Left lane	Right lane		
2011/10/3	8	16:50		4		0			4	32.0
2011/10/3	8	17:17		2		0			2	16.0
2011/10/3	9	16:57		0		0			0	0.0
2011/10/3	29	16:35		0		0			0	0.0
2011/10/3	29	17:36		0		0			0	0.0
2011/10/3	200	17:20		2		0			2	16.0
2011/10/3	7	17:42		5		0			5	39.9
2011/10/4	8	16:47		0		0			0	0.0
2011/10/4	9	16:46		3		0			3	24.0
2011/10/4	200	16:42		5		2			9.5	75.9
2011/10/4	7	16:41		4		1			6.25	49.9
2011/10/5	8	16:55		0		0			0	0.0
2011/10/5	8	17:37		1		1			3.25	26.0
2011/10/5	12	17:46		12		1			14.25	113.8
2011/10/5	12	17:47		0		0			0	0.0
2011/10/5	13	17:45		8		1			10.25	81.9
2011/10/5	29	17:37		1		0			1	8.0
2011/10/5	29	17:52		1		0			1	8.0
2011/10/5	200	16:43		0		1			2.25	18.0
2011/10/5	200	16:54		7		0			7	55.9
2011/10/5	200	17:07		0		0			0	0.0
2011/10/5	200	17:17		3		0			3	24.0
2011/10/5	200	17:42		11		0			11	87.9
2011/10/5	200	17:45		7		0			7	55.9
2011/10/5	7	16:43		0		0			0	0.0
2011/10/5	7	16:57		2		1			4.25	34.0
2011/10/5	7	17:29		4		0			4	32.0
2011/10/5	7	17:46		12		0			12	95.9
2011/10/6	8	16:37		8		0			8	63.9
2011/10/6	8	16:45		0		0			0	0.0
2011/10/6	8	17:46		2		1			4.25	34.0
2011/10/6	8	17:47						217		217.0
2011/10/6	8	17:47		7		2			11.5	91.9
2011/10/6	8	17:51		7		1			9.25	73.9
2011/10/6	9	17:38		15		2			19.5	155.8
2011/10/6	9	17:38		3		0			3	24.0
2011/10/6	12	17:12		19		1			21.25	169.8

Date	Route	Time	Number of vehicles in downstream of bus				Position measured by reference lines (metres)		PCU	Distance of bus to stopline (meters)
			Passenger cars		Heavy vehicles					
			Left lane	Right lane	Left lane	Right lane	Left lane	Right lane		
2011/10/6	12	17:13		5		1			7.25	57.9
2011/10/6	12	17:18		4		0			4	32.0
2011/10/6	12	17:41		15		1			17.25	137.8
2011/10/6	12	17:42		3		0			3	24.0
2011/10/6	12	17:49		8		0			8	63.9
2011/10/6	13	17:46		13		2			17.5	139.8
2011/10/6	13	17:47		1		0			1	8.0
2011/10/6	29	16:34		1		0			1	8.0
2011/10/6	29	16:49		2		0			2	16.0
2011/10/6	29	17:03		5		0			5	39.9
2011/10/6	29	17:20		10		0			10	79.9
2011/10/6	29	17:35		19		0			19	151.8
2011/10/6	29	17:37		3		0			3	24.0
2011/10/6	29	17:51		6		0			6	47.9
2011/10/6	7	17:12						144		144.0
2011/10/6	7	17:13		3		0			3	24.0
2011/10/6	7	17:27		7		0			7	55.9
2011/10/6	7	17:48		6		3			12.75	101.9
2011/10/6	200	16:32		0		0			0	0.0
2011/10/6	200	16:39		0		0			0	0.0
2011/10/6	200	17:07		3		0			3	24.0
2011/10/6	200	17:15		7		0			7	55.9
2011/10/6	200	17:27		4		0			4	32.0
2011/10/6	200	17:39		12		1			14.25	113.8
2011/10/6	200	17:40		2		0			2	16.0
2011/10/6	200	17:47						199		199.0
2011/10/6	200	17:47		6		1			8.25	65.9
2011/10/7	8	16:37		0		0			0	0.0
2011/10/7	8	17:08		0		0			0	0.0
2011/10/7	29	16:49		4		0			4	32.0
2011/10/7	200	17:16		4		0			4	32.0
2011/10/11	8	16:30		0		0			0	0.0
2011/10/11	8	16:50		1		1			3.25	26.0
2011/10/11	29	16:48		4		1			6.25	49.9
2011/10/11	7	17:30		7		0			7	55.9
2011/10/11	200	16:39		1		0			1	8.0
2011/10/11	200	17:10		0		0			0	0.0

Date	Route	Time	Number of vehicles in downstream of bus				Position measured by reference lines (metres)		PCU	Distance of bus to stopline (meters)
			Passenger cars		Heavy vehicles					
			Left lane	Right lane	Left lane	Right lane	Left lane	Right lane		
2011/10/11	200	17:32		0		0			0	0.0
2011/10/11	200	17:43		0		0			0	0.0
2011/10/12	8	16:48		13		0			13	103.9
2011/10/12	8	16:49		0		0			0	0.0
2011/10/12	8	17:05		0		0			0	0.0
2011/10/12	8	17:38		0		0			0	0.0
2011/10/12	8	17:45		2		0			2	16.0
2011/10/12	12	16:42		14		2			18.5	147.8
2011/10/12	12	16:44		0		0			0	0.0
2011/10/12	12	17:30		0		0			0	0.0
2011/10/12	29	16:51		0		0			0	0.0
2011/10/12	29	17:29		11		0			11	87.9
2011/10/12	200	16:41		6		0			6	47.9
2011/10/12	200	16:49		2		1			4.25	34.0
2011/10/12	200	17:16		5		1			7.25	57.9
2011/10/12	200	17:25		8		0			8	63.9
2011/10/12	7	16:41		6		1			8.25	65.9
2011/10/12	7	17:38		1		1			3.25	26.0
2011/10/13	8	17:34		3		0			3	24.0
2011/10/13	8	17:48		0		0			0	0.0
2011/10/13	12	17:45		8		0			8	63.9
2011/10/13	12	17:45		1		0			1	8.0
2011/10/13	29	16:34		0		0			0	0.0
2011/10/13	29	16:50		6		0			6	47.9
2011/10/13	29	17:20		0		0			0	0.0
2011/10/13	7	16:37		9		0			9	71.9
2011/10/13	7	16:57		7		0			7	55.9
2011/10/13	7	17:25		1		0			1	8.0
2011/10/13	200	17:16		0		0			0	0.0
2011/10/13	200	17:23		3		0			3	24.0
2011/10/14	8	16:57		1					1	8.0
2011/10/14	8	17:12		0		0			0	0.0
2011/10/14	8	17:24		12		0			12	95.9
2011/10/14	9	16:32		3		1			5.25	41.9
2011/10/14	9	17:17		11		1			13.25	105.9
2011/10/14	12	16:47		8		1			10.25	81.9
2011/10/14	12	16:49		0		0			0	0.0

Date	Route	Time	Number of vehicles in downstream of bus				Position measured by reference lines (metres)		PCU	Distance of bus to stopline (meters)
			Passenger cars		Heavy vehicles					
			Left lane	Right lane	Left lane	Right lane	Left lane	Right lane		
2011/10/14	12	17:17		5		0			5	39.9
2011/10/14	29	16:51		1					1	8.0
2011/10/14	29	17:08	4		0				4	32.0
2011/10/14	29	17:23		10		0			10	79.9
2011/10/14	200	17:10		6					6	47.9
2011/10/14	200	17:14		2		1			4.25	34.0
2011/10/14	7	17:13		0		0			0	0.0
2011/10/17	8	17:10		0		0			0	0.0
2011/10/17	8	17:36		0		1			2.25	18.0
2011/10/17	9	17:03		0		0			0	0.0
2011/10/17	29	16:35		4		0			4	32.0
2011/10/17	29	17:20		2		0			2	16.0
2011/10/17	29	17:36		0		0			0	0.0
2011/10/17	200	17:13		5		0			5	39.9
2011/10/17	200	17:40		4		0			4	32.0
2011/10/17	7	17:12		3		0			3	24.0

Appendix D. Observed bus travel time within field segment

Stop ID	Trip ID	Date	Route	Entry	Exit	Actual Travel Time(s)
78913371	78913344	2011/10/3	7	16:40:06	16:40:37	31
78913452	78913420	2011/10/3	7	17:41:50	17:42:41	51
78790921	78790915	2011/10/3	8	17:18:57	17:20:26	89
78872433	78872373	2011/10/3	200	16:45:19	16:45:56	37
78859814	78859761	2011/10/3	200	17:21:03	17:22:15	72
78778678	78778627	2011/10/3	200	17:31:33	17:31:54	21
79028970	79028940	2011/10/4	7	16:42:33	16:43:18	45
79025443	79025419	2011/10/4	7	17:10:12	17:10:30	18
79024138	79024130	2011/10/4	8	16:46:55	16:48:03	68
79020413	79020373	2011/10/4	12	16:44:33	16:44:52	19
79280343	79280308	2011/10/5	7	16:40:20	16:41:21	61
79244742	79244713	2011/10/5	7	17:11:01	17:11:35	34
79281653	79281616	2011/10/5	7	17:28:06	17:29:45	99
79280428	79280392	2011/10/5	7	17:43:47	17:44:44	57
79345937	79345896	2011/10/5	12	17:43:58	17:45:59	121
79345938	79345896	2011/10/5	12	17:43:58	17:45:59	121
79275439	79275431	2011/10/5	29	17:35:33	17:36:49	76
79266556	79266489	2011/10/5	200	16:40:27	16:41:37	70
79270339	79270275	2011/10/5	200	16:51:35	16:53:13	98
79270340	79270275	2011/10/5	200	16:51:35	16:53:13	98
79261964	79261902	2011/10/5	200	17:00:05	17:00:46	41
79267257	79267187	2011/10/5	200	17:40:18	17:41:15	57
79486307	79486274	2011/10/6	7	17:12:07	17:14:21	134
79486308	79486274	2011/10/6	7	17:12:07	17:14:21	134
79420412	79420382	2011/10/6	7	17:27:02	17:28:59	117
79527294	79527260	2011/10/6	7	17:47:35	17:49:33	118
79517566	79517559	2011/10/6	8	16:45:01	16:46:28	87
79515077	79515069	2011/10/6	8	17:51:08	17:52:50	102
79515078	79515069	2011/10/6	8	17:51:08	17:52:50	102
79490244	79490202	2011/10/6	12	17:17:47	17:19:37	110
79508075	79508067	2011/10/6	12	17:40:59	17:43:33	154
79508076	79508067	2011/10/6	12	17:40:59	17:43:33	154
79446022	79445979	2011/10/6	12	17:48:51	17:51:07	136
79446023	79445979	2011/10/6	12	17:48:51	17:51:07	136
79364453	79364444	2011/10/6	29	16:48:59	16:50:10	71
79408531	79408524	2011/10/6	29	17:19:38	17:21:46	128
79408532	79408524	2011/10/6	29	17:19:38	17:21:46	128
79475988	79475981	2011/10/6	29	17:50:56	17:52:41	105
79475989	79475981	2011/10/6	29	17:50:56	17:52:41	105
79464011	79463941	2011/10/6	200	16:32:12	16:32:51	39

Stop ID	Trip ID	Date	Route	Entry	Exit	Actual Travel Time(s)
79530661	79530588	2011/10/6	200	17:07:04	17:08:35	91
79458955	79458899	2011/10/6	200	17:14:01	17:16:07	126
79458956	79458899	2011/10/6	200	17:14:01	17:16:07	126
79532022	79531947	2011/10/6	200	17:26:48	17:28:48	120
79532023	79531947	2011/10/6	200	17:26:48	17:28:48	120
79463347	79463273	2011/10/6	200	17:38:34	17:41:43	189
79463348	79463273	2011/10/6	200	17:38:34	17:41:43	189
79536212	79536155	2011/10/6	200	17:46:57	17:49:13	136
79536213	79536155	2011/10/6	200	17:46:57	17:49:13	136
79854652	79854644	2011/10/7	8	17:42:26	17:43:11	45
80058041	80058033	2011/10/7	29	16:48:58	16:49:34	36
80264653	80264624	2011/10/11	7	17:29:40	17:30:38	58
80340035	80340028	2011/10/11	8	16:49:44	16:51:38	114
80307357	80307351	2011/10/11	29	16:47:29	16:48:33	64
80358018	80357959	2011/10/11	200	16:38:57	16:40:36	99
80825493	80825422	2011/10/17	200	17:12:30	17:14:22	112

Appendix E. AVL/APC stopped delay vs. observed total delay

Stop ID	Trip ID	Date	Route	AVL/APC Time	AVL/APC Stopped Delay	Entry	Exit	Observed Total Delay(s)	AVL/APC Total Trip Delay(s)
78913371	78913344	2011/10/3	7	16:40:54	4	16:40:06	16:40:37	13.7	4
78913452	78913420	2011/10/3	7	17:42:28	15	17:41:50	17:42:41	33.7	15
78790921	78790915	2011/10/3	8	17:19:48	60	17:18:57	17:20:26	71.7	60
78872433	78872373	2011/10/3	200	16:46:21	0	16:45:19	16:45:56	19.7	0
78859814	78859761	2011/10/3	200	17:21:42	45	17:21:03	17:22:15	54.7	45
78778678	78778627	2011/10/3	200	17:32:05	2	17:31:33	17:31:54	3.7	2
79028970	79028940	2011/10/4	7	16:43:34	2	16:42:33	16:43:18	27.7	2
79025443	79025419	2011/10/4	7	17:10:46	0	17:10:12	17:10:30	0.7	0
79024138	79024130	2011/10/4	8	16:47:43	38	16:46:55	16:48:03	50.7	38
79020413	79020373	2011/10/4	12	16:45:03	0	16:44:33	16:44:52	1.7	0
79280343	79280308	2011/10/5	7	16:41:15	16	16:40:20	16:41:21	43.7	16
79244742	79244713	2011/10/5	7	17:12:01	1	17:11:01	17:11:35	16.7	1
79281653	79281616	2011/10/5	7	17:28:55	55	17:28:06	17:29:45	81.7	55
79280428	79280392	2011/10/5	7	17:44:29	15	17:43:47	17:44:44	39.7	15
79345937	79345896	2011/10/5	12	17:44:44	5	17:43:58	17:45:59		
79345938	79345896	2011/10/5	12	17:45:20	67	17:43:58	17:45:59	103.7	72
79275439	79275431	2011/10/5	29	17:36:33	36	17:35:33	17:36:49	58.7	36
79266556	79266489	2011/10/5	200	16:41:23	33	16:40:27	16:41:37	52.7	33
79270339	79270275	2011/10/5	200	16:52:29	43	16:51:35	16:53:13		
79270340	79270275	2011/10/5	200	16:53:38	3	16:51:35	16:53:13	80.7	46
79261964	79261902	2011/10/5	200	17:00:57	4	17:00:05	17:00:46	23.7	4
79267257	79267187	2011/10/5	200	17:41:15	6	17:40:18	17:41:15	39.7	6
79486307	79486274	2011/10/6	7	17:12:49	11	17:12:07	17:14:21		
79486308	79486274	2011/10/6	7	17:13:28	62	17:12:07	17:14:21	116.7	73
79420412	79420382	2011/10/6	7	17:28:14	63	17:27:02	17:28:59	99.7	63
79527294	79527260	2011/10/6	7	17:48:36	58	17:47:35	17:49:33	100.7	58
79517566	79517559	2011/10/6	8	16:46:12	37	16:45:01	16:46:28	69.7	37
79515077	79515069	2011/10/6	8	17:51:43	4	17:51:08	17:52:50		
79515078	79515069	2011/10/6	8	17:52:20	43	17:51:08	17:52:50	84.7	47
79490244	79490202	2011/10/6	12	17:18:58	57	17:17:47	17:19:37	92.7	57
79508075	79508067	2011/10/6	12	17:41:57	27	17:40:59	17:43:33		
79508076	79508067	2011/10/6	12	17:42:58	59	17:40:59	17:43:33	136.7	86
79446022	79445979	2011/10/6	12	17:49:35	9	17:48:51	17:51:07		
79446023	79445979	2011/10/6	12	17:50:22	60	17:48:51	17:51:07	118.7	69
79364453	79364444	2011/10/6	29	16:49:49	36	16:48:59	16:50:10	53.7	36
79408531	79408524	2011/10/6	29	17:20:22	2	17:19:38	17:21:46		
79408532	79408524	2011/10/6	29	17:20:57	58	17:19:38	17:21:46	110.7	60
79475988	79475981	2011/10/6	29	17:51:34	10	17:50:56	17:52:41	87.7	55

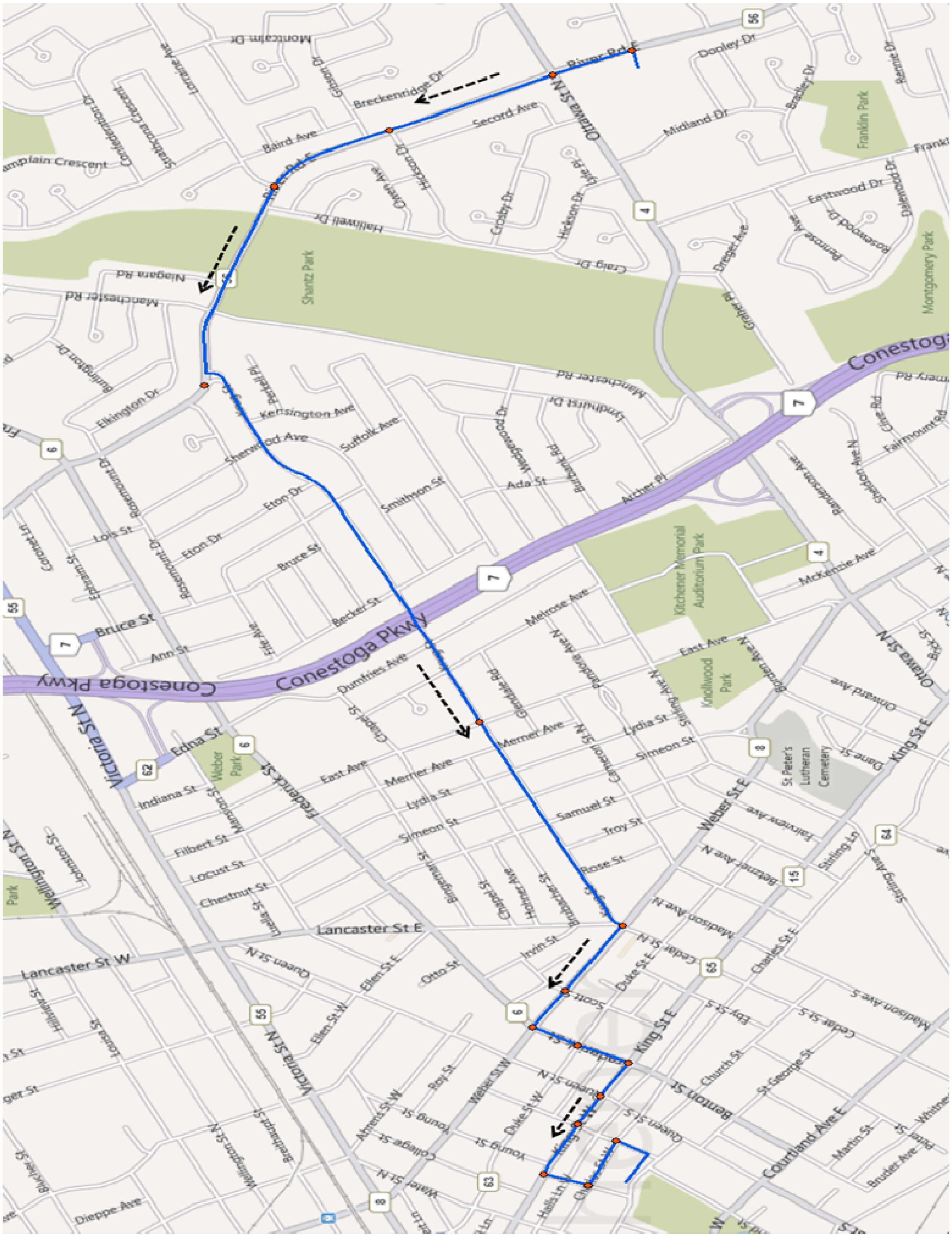
Stop ID	Trip ID	Date	Route	AVL/APC Time	AVL/APC Stopped Delay	Entry	Exit	Observed Total Delay(s)	AVL/APC Total Trip Delay(s)
79475989	79475981	2011/10/6	29	17:52:15	45	17:50:56	17:52:41		
79464011	79463941	2011/10/6	200	16:33:07	1	16:32:12	16:32:51	21.7	1
79530661	79530588	2011/10/6	200	17:08:00	65	17:07:04	17:08:35	73.7	65
79458955	79458899	2011/10/6	200	17:14:41	16	17:14:01	17:16:07		
79458956	79458899	2011/10/6	200	17:15:35	42	17:14:01	17:16:07	108.7	58
79532022	79531947	2011/10/6	200	17:27:47	0	17:26:48	17:28:48		
79532023	79531947	2011/10/6	200	17:28:08	68	17:26:48	17:28:48	102.7	68
79463347	79463273	2011/10/6	200	17:39:35	50	17:38:34	17:41:43		
79463348	79463273	2011/10/6	200	17:41:05	54	17:38:34	17:41:43	171.7	104
79536212	79536155	2011/10/6	200	17:47:38	11	17:46:57	17:49:13		
79536213	79536155	2011/10/6	200	17:48:27	59	17:46:57	17:49:13	118.7	70
79854652	79854644	2011/10/7	8	17:43:25	1	17:42:26	17:43:11	27.7	1
80058041	80058033	2011/10/7	29	16:49:49	1	16:48:58	16:49:34	18.7	1
80264653	80264624	2011/10/11	7	17:30:50	10	17:29:40	17:30:38	40.7	10
80340035	80340028	2011/10/11	8	16:51:03	56	16:49:44	16:51:38	96.7	56
80307357	80307351	2011/10/11	29	16:48:33	19	16:47:29	16:48:33	46.7	19
80358018	80357959	2011/10/11	200	16:40:08	49	16:38:57	16:40:36	81.7	49
80825493	80825422	2011/10/17	200	17:14:00	37	17:12:30	17:14:22	94.7	37

Appendix F. AVL/APC data for application in maximum queue extent validation

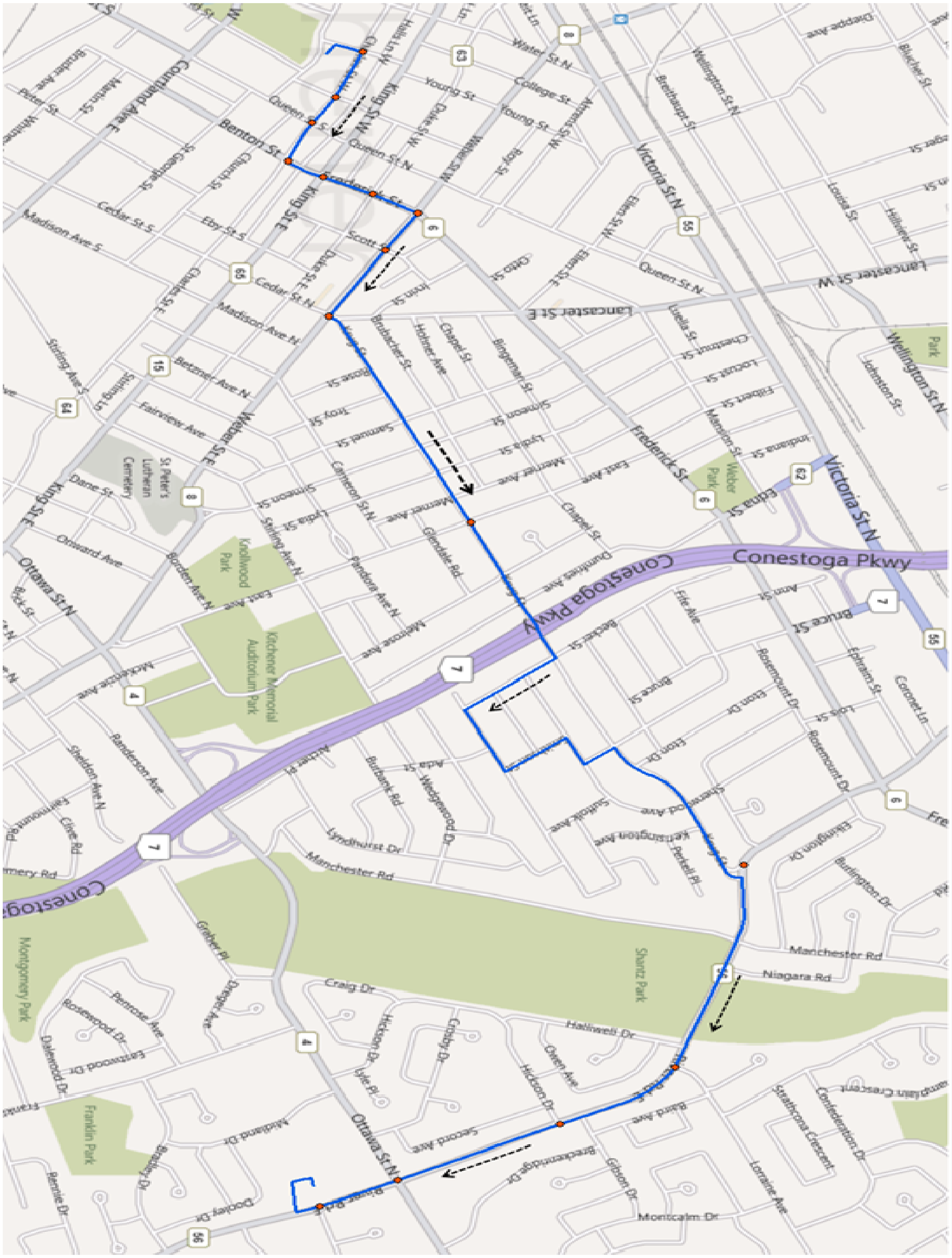
ID	TRIP_ID	OP_DAY	ACT_ARR_TIME_HHMMSS	ACT_DEP_TIME_HHMMSS	LONGITUDE	LATITUDE
80803979	80803972	2011/10/17	16:19:44	16:19:45	-80.538793	43.46946
79107424	79107392	2011/10/4	16:02:04	16:02:46	-80.538968	43.469167
79020413	79020373	2011/10/4	16:45:03	16:45:03	-80.538293	43.470533
78948133	78948126	2011/10/4	15:19:44	15:20:22	-80.539128	43.468912
78926548	78926516	2011/10/3	17:09:59	17:10:09	-80.539035	43.469052
79107345	79107286	2011/10/4	15:01:17	15:01:43	-80.539127	43.4689
79854652	79854644	2011/10/7	17:43:25	17:43:26	-80.53891	43.46921
80058041	80058033	2011/10/7	16:49:49	16:49:50	-80.53895	43.469202
79139443	79139436	2011/10/4	15:29:57	15:29:57	-80.539018	43.469037
78939369	78939312	2011/10/3	17:49:25	17:49:25	-80.538793	43.469952
78778678	78778627	2011/10/3	17:32:05	17:32:07	-80.538725	43.469622
79090834	79090827	2011/10/4	15:20:52	15:20:43	-80.538355	43.470352
79123471	79123438	2011/10/4	17:29:29	17:29:29	-80.538275	43.470512
79022566	79022558	2011/10/4	15:04:16	15:04:16	-80.539043	43.469017
78766855	78766815	2011/10/3	17:47:06	17:48:15	-80.539077	43.46894
78872433	78872373	2011/10/3	16:46:21	16:46:21	-80.539207	43.468862
79057707	79057652	2011/10/4	17:51:48	17:51:49	-80.539102	43.468908
78864870	78864801	2011/10/3	17:52:17	17:52:17	-80.539228	43.468822
78933879	78933871	2011/10/3	15:49:23	15:49:23	-80.539055	43.469018
79135325	79135291	2011/10/4	16:26:02	16:26:03	-80.538818	43.469943
79028970	79028940	2011/10/4	16:43:34	16:43:36	-80.538955	43.469228
78800136	78800129	2011/10/3	15:49:48	15:50:39	-80.539105	43.468933
78936245	78936186	2011/10/3	15:06:02	15:06:38	-80.53904	43.469007
79141849	79141843	2011/10/4	17:34:58	17:34:59	-80.538712	43.46965
79054097	79054026	2011/10/4	15:32:48	15:32:48	-80.538705	43.470058
78769385	78769345	2011/10/3	15:16:01	15:16:03	-80.538908	43.469282
79024138	79024130	2011/10/4	16:47:43	16:48:21	-80.539097	43.468947
79025443	79025419	2011/10/4	17:10:46	17:10:46	-80.538872	43.469348
78913452	78913420	2011/10/3	17:42:28	17:42:43	-80.538907	43.469308
78859814	78859761	2011/10/3	17:21:42	17:22:27	-80.53904	43.469048
78790921	78790915	2011/10/3	17:19:48	17:20:48	-80.538995	43.469077
78913371	78913344	2011/10/3	16:40:54	16:40:58	-80.539118	43.468878
78884014	78884007	2011/10/3	15:20:09	15:20:09	-80.539095	43.4689
78884013	78884007	2011/10/3	15:19:51	15:19:57	-80.539073	43.468942
80222868	80222860	2011/10/11	15:50:35	15:51:30	-80.539082	43.468947
80307357	80307351	2011/10/11	16:48:33	16:48:52	-80.538945	43.46924
80274979	80274920	2011/10/11	16:01:12	16:01:14	-80.539012	43.469092
80337461	80337453	2011/10/11	15:22:22	15:22:23	-80.538397	43.470285
80282319	80282248	2011/10/11	15:52:37	15:53:26	-80.539067	43.468998
80342158	80342152	2011/10/11	15:28:55	15:29:20	-80.539073	43.468968
80345142	80345133	2011/10/11	15:27:27	15:27:30	-80.53827	43.470528
80220882	80220851	2011/10/11	16:01:14	16:01:15	-80.539178	43.46884
80279852	80279778	2011/10/11	15:11:53	15:11:53	-80.539305	43.468818
80362190	80362157	2011/10/11	15:44:24	15:44:25	-80.538915	43.46926
80240970	80240940	2011/10/11	16:11:55	16:11:56	-80.538862	43.469402
80264653	80264624	2011/10/11	17:30:50	17:31:00	-80.53882	43.469418

ID	TRIP_ID	OP_DAY	ACT_ARR_TIME_HHMMSS	ACT_DEP_TIME_HHMMSS	LONGITUDE	LATITUDE
80358018	80357959	2011/10/11	16:40:08	16:40:57	-80.539028	43.46898
80340035	80340028	2011/10/11	16:51:03	16:51:59	-80.538987	43.469113
80825493	80825422	2011/10/17	17:14:00	17:14:37	-80.538832	43.469378
80829521	80829451	2011/10/17	15:54:02	15:54:20	-80.539015	43.469082

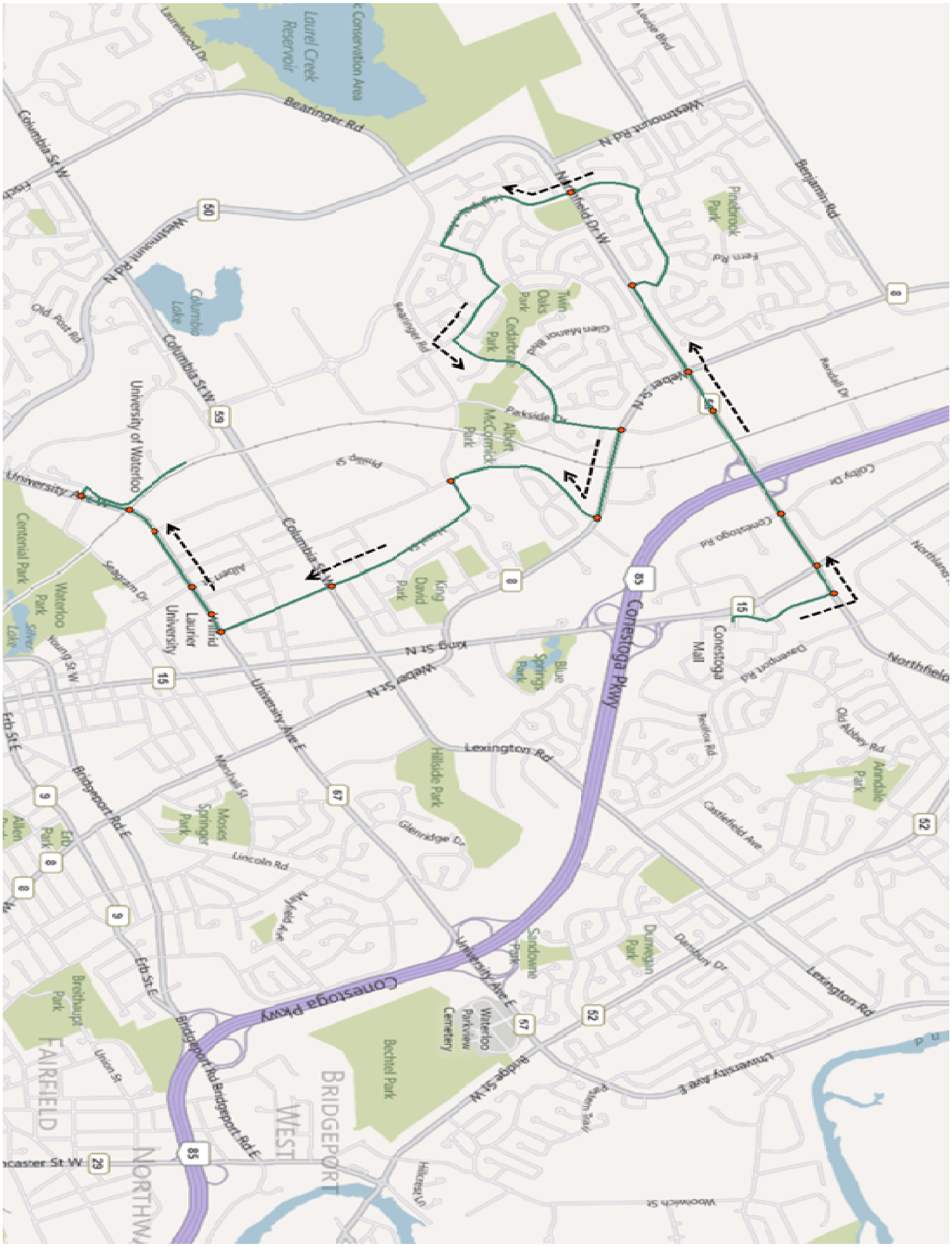
Appendix G. Study route alignment



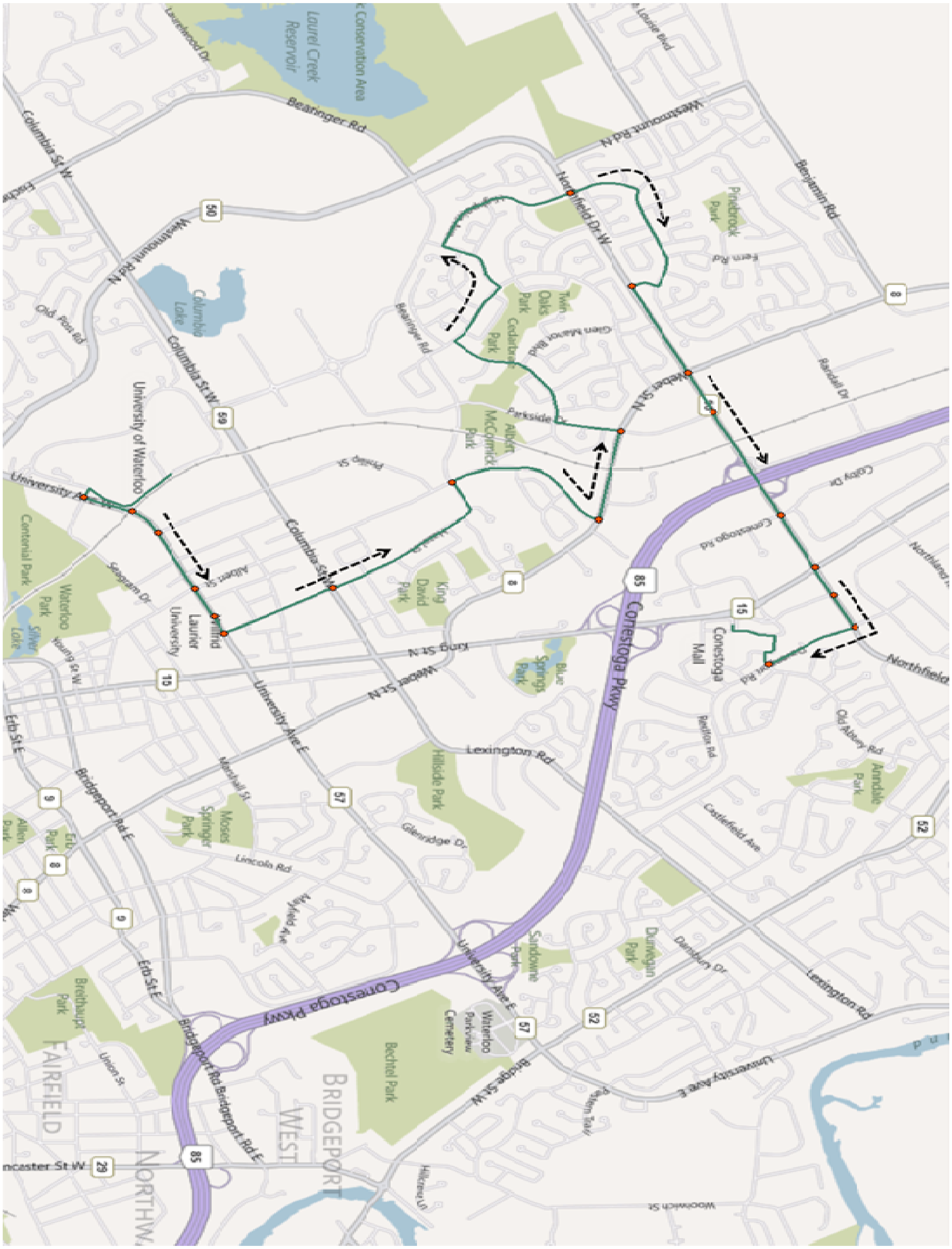
Route 1/Inbound



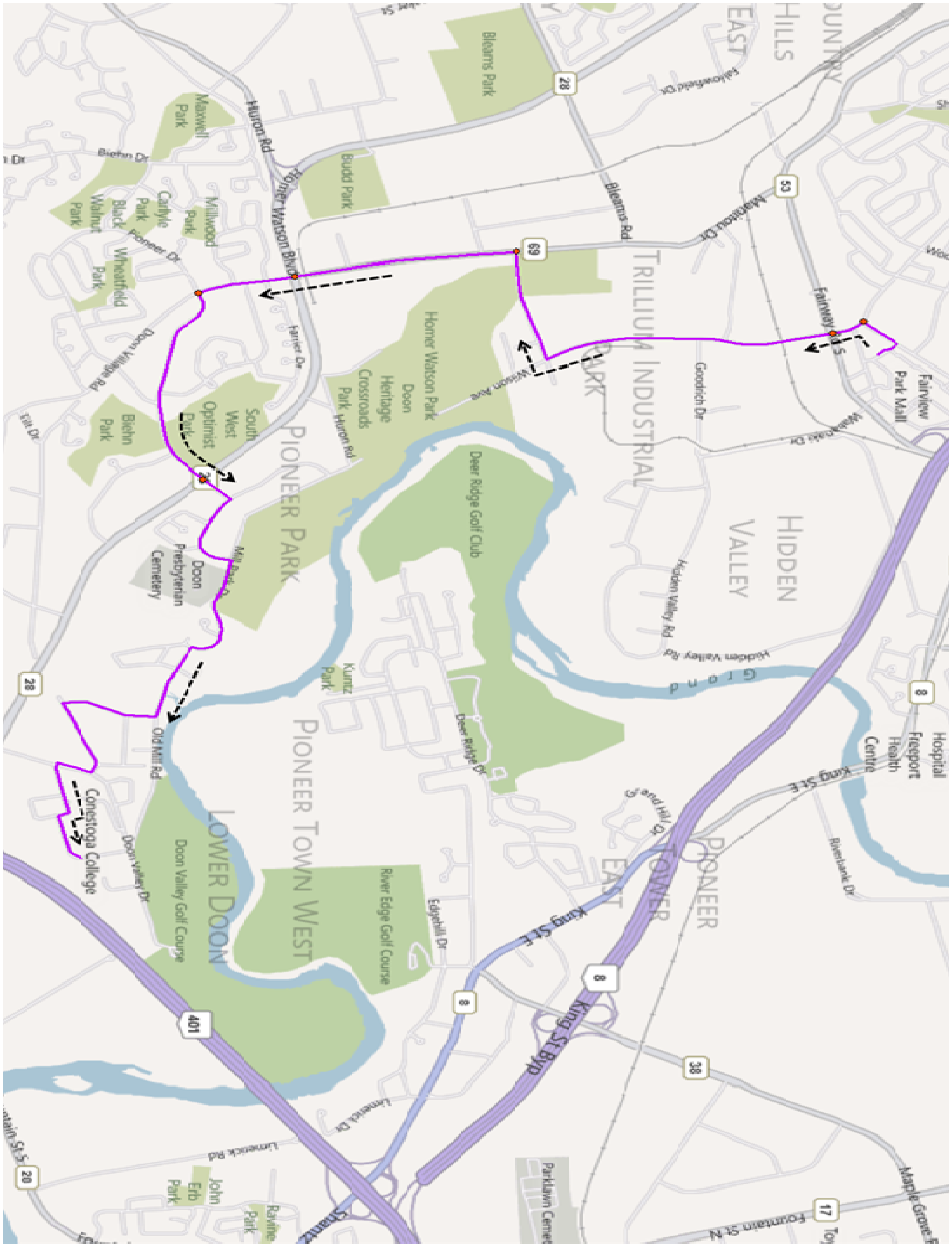
Route 1/Outbound



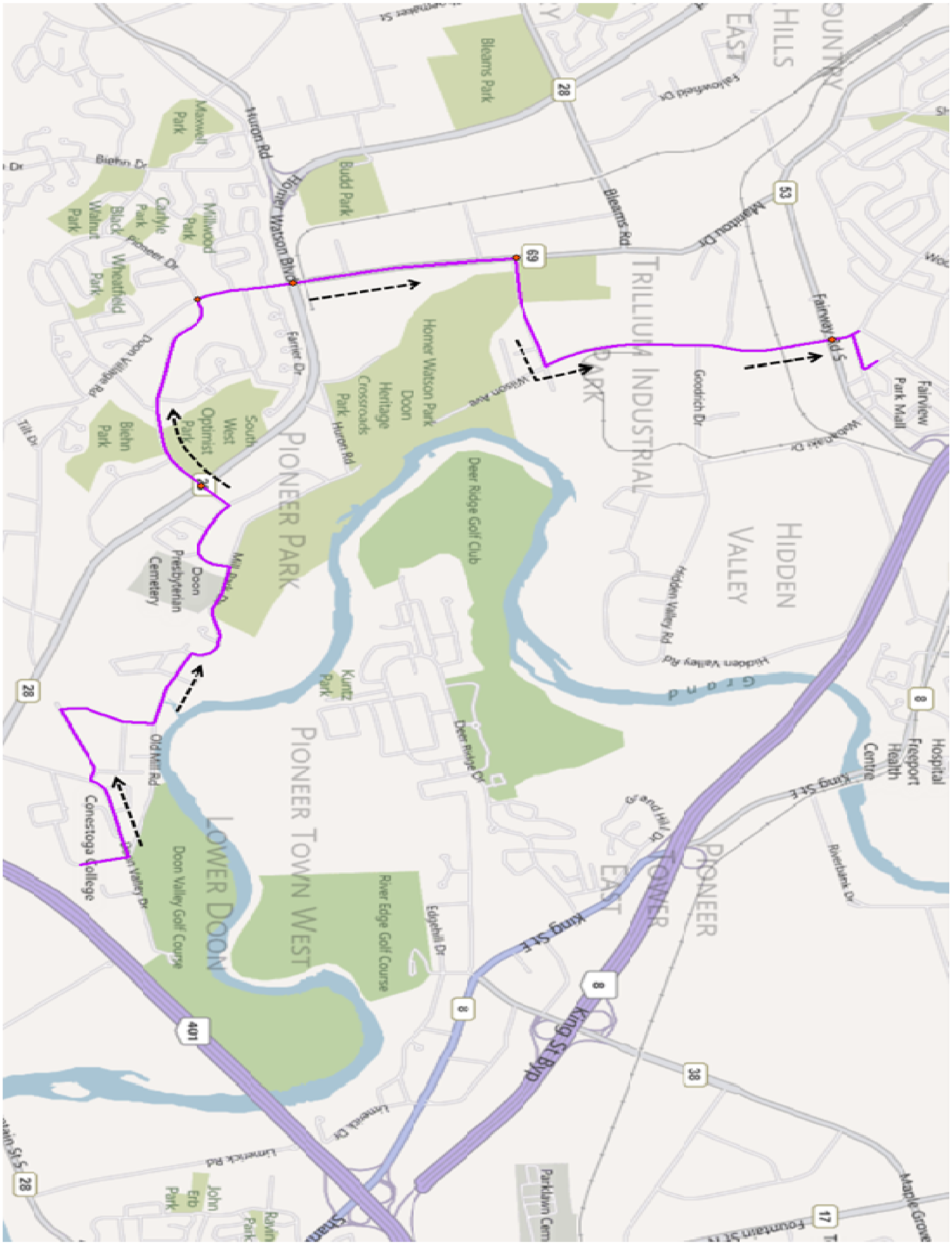
Route 9/Downward



Route 9/Upward

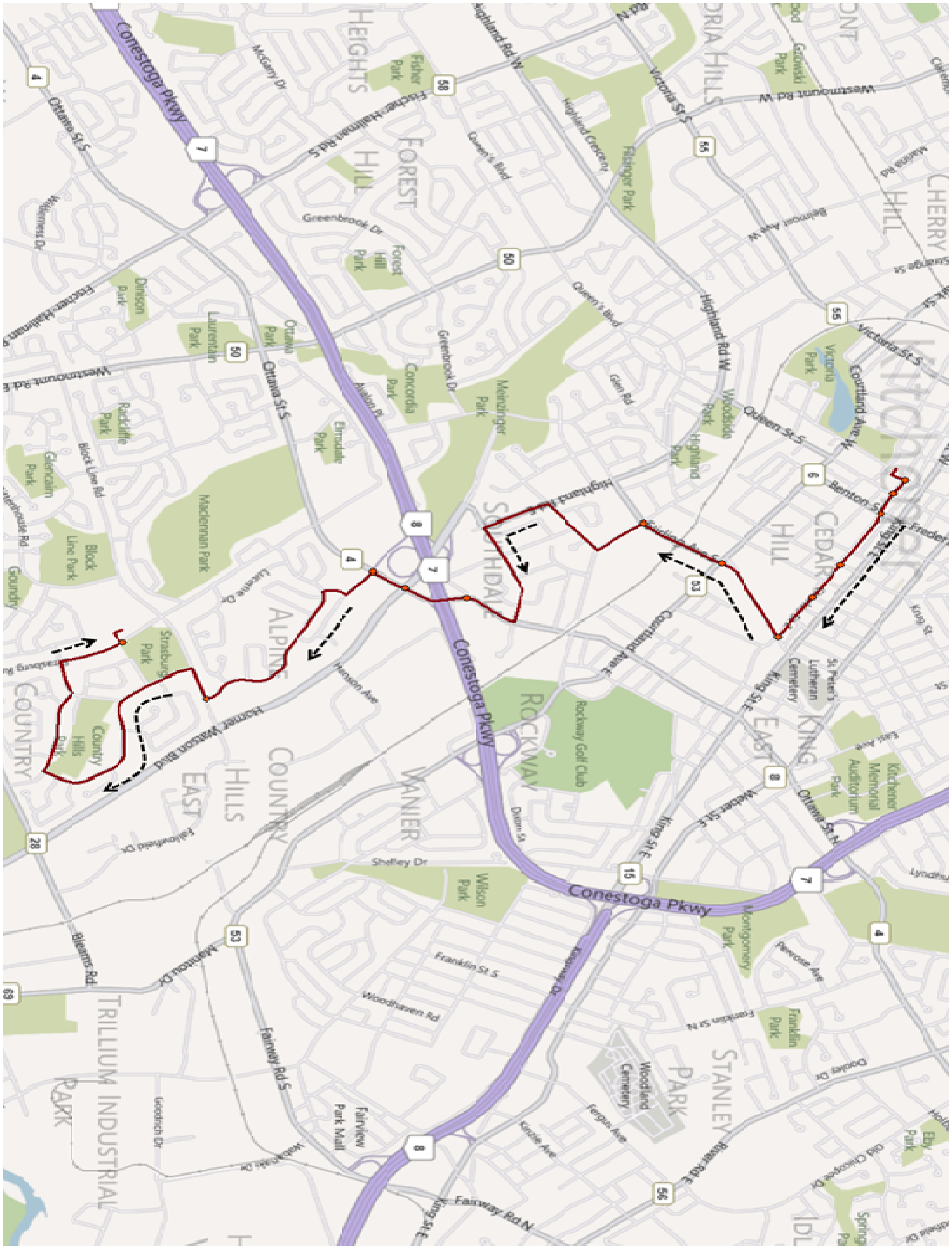


Route 10/Downward



Route 10/Upward

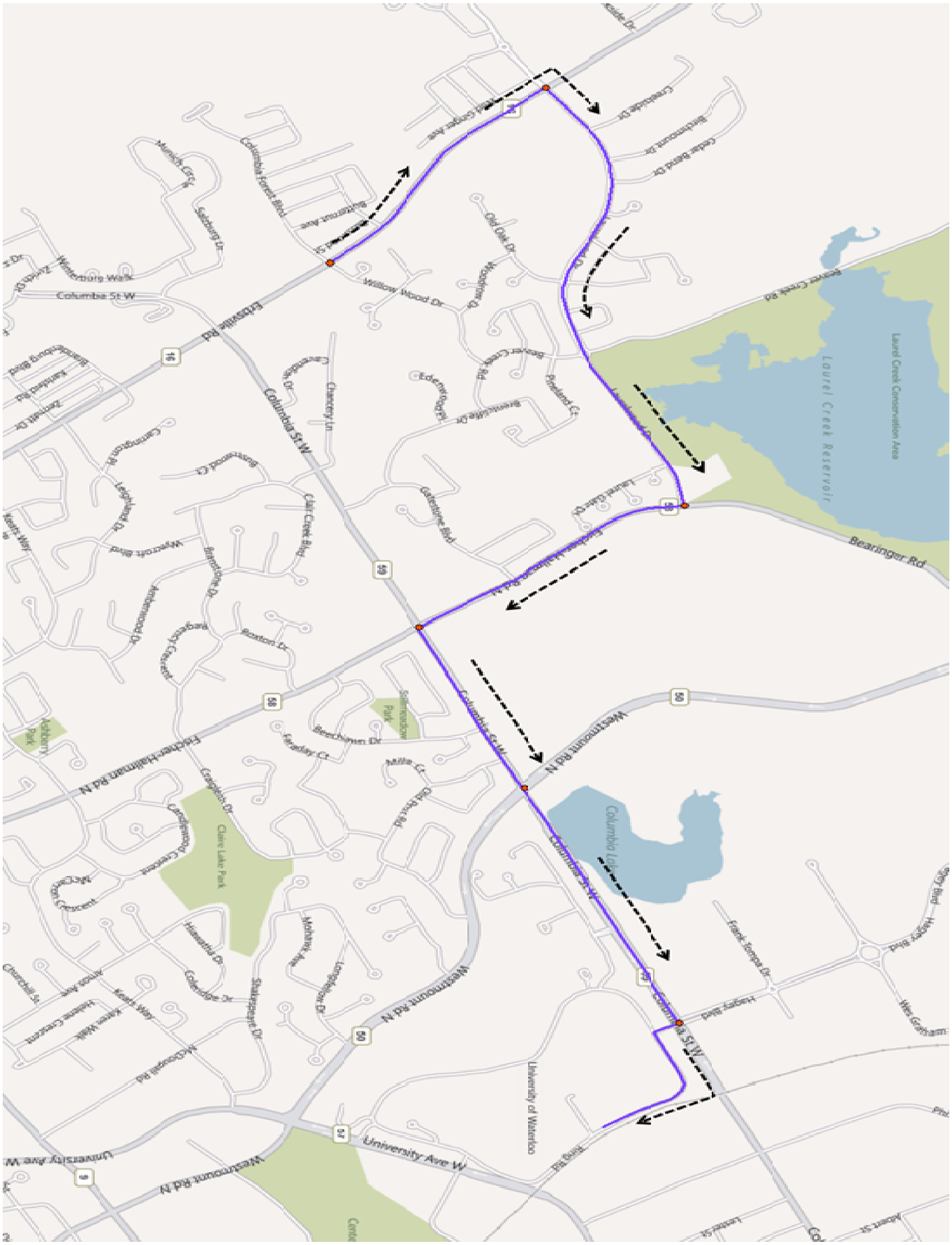
Route 11/Inbound



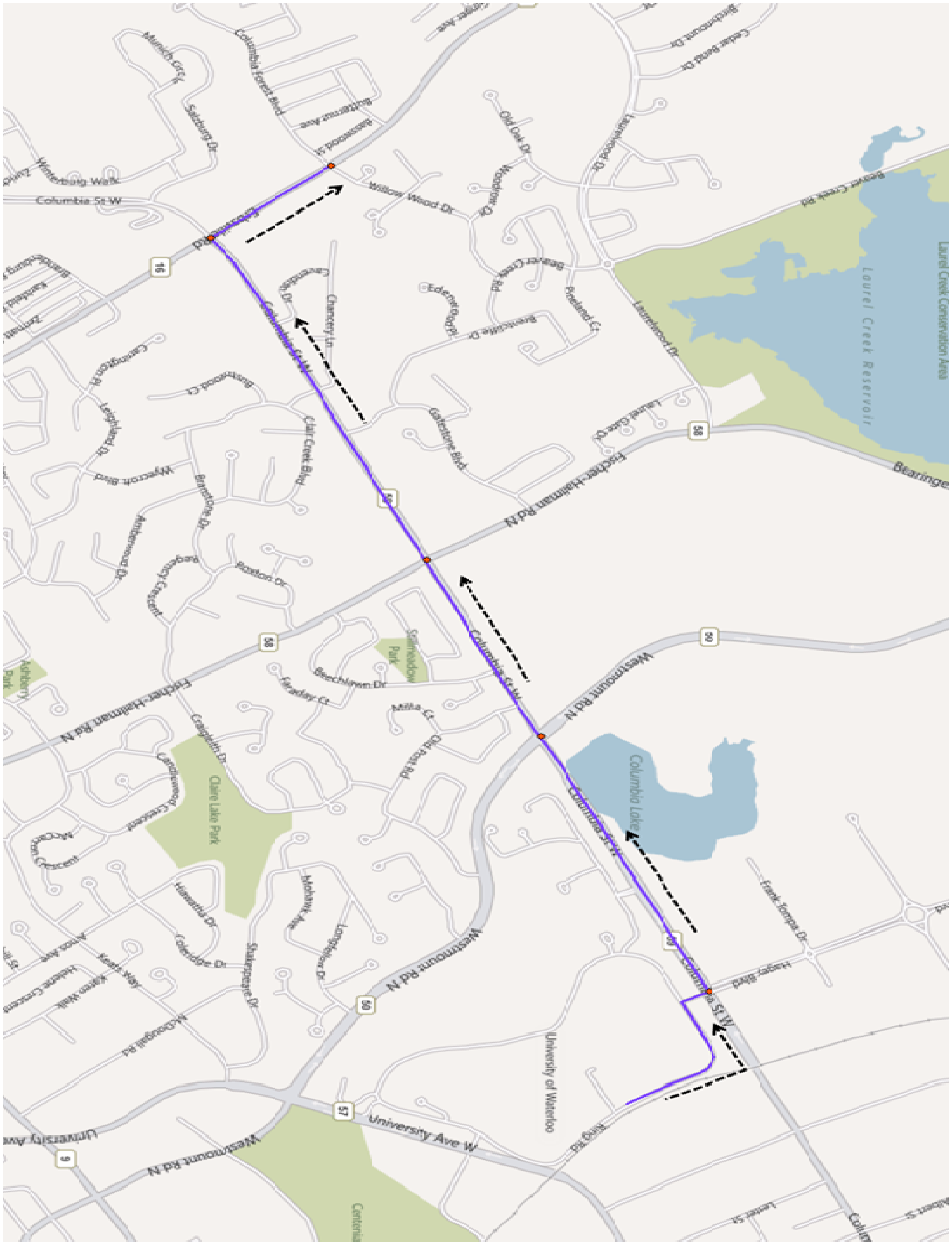
Route 11/Outbound

Route 12/Downward

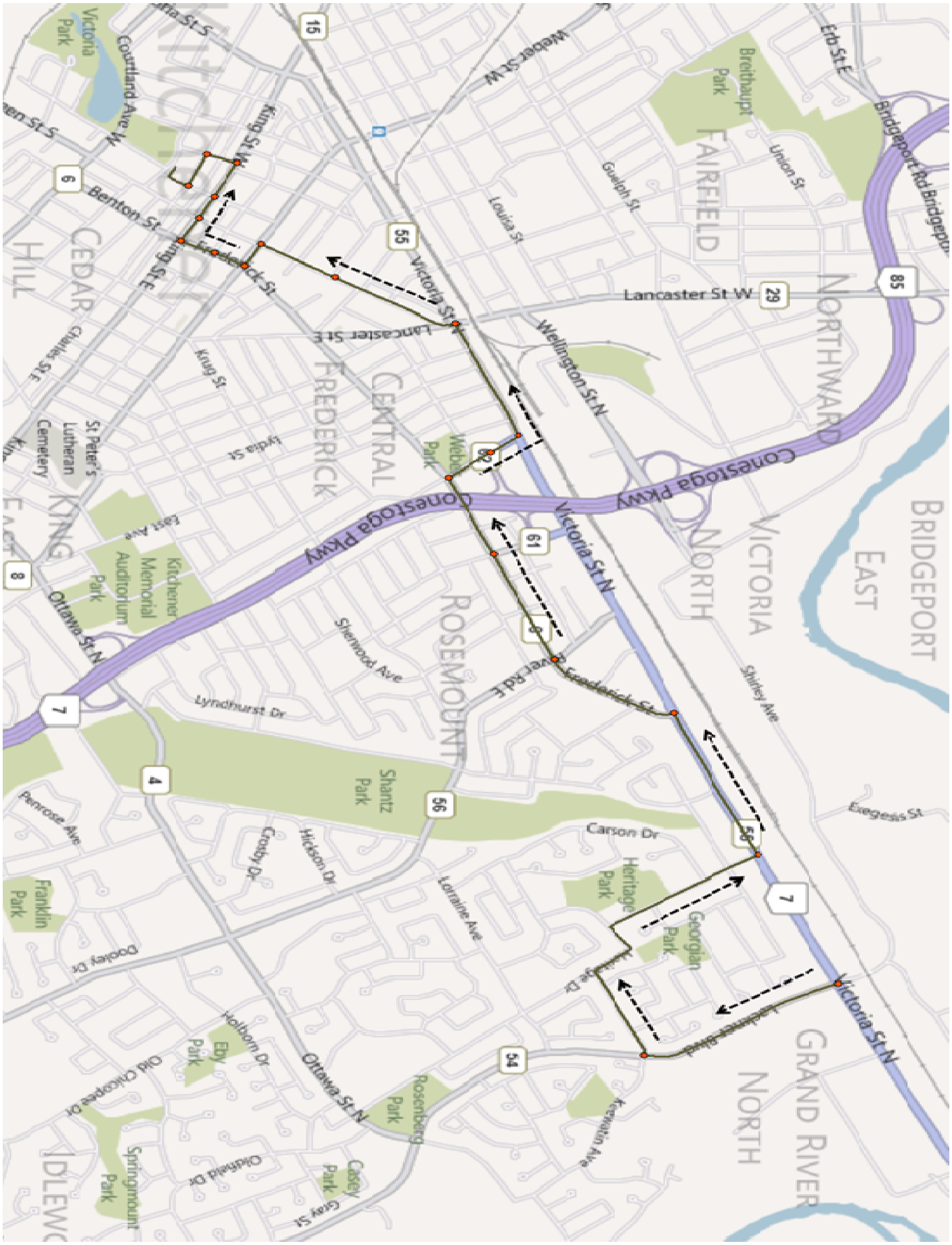
Route 12/Upward



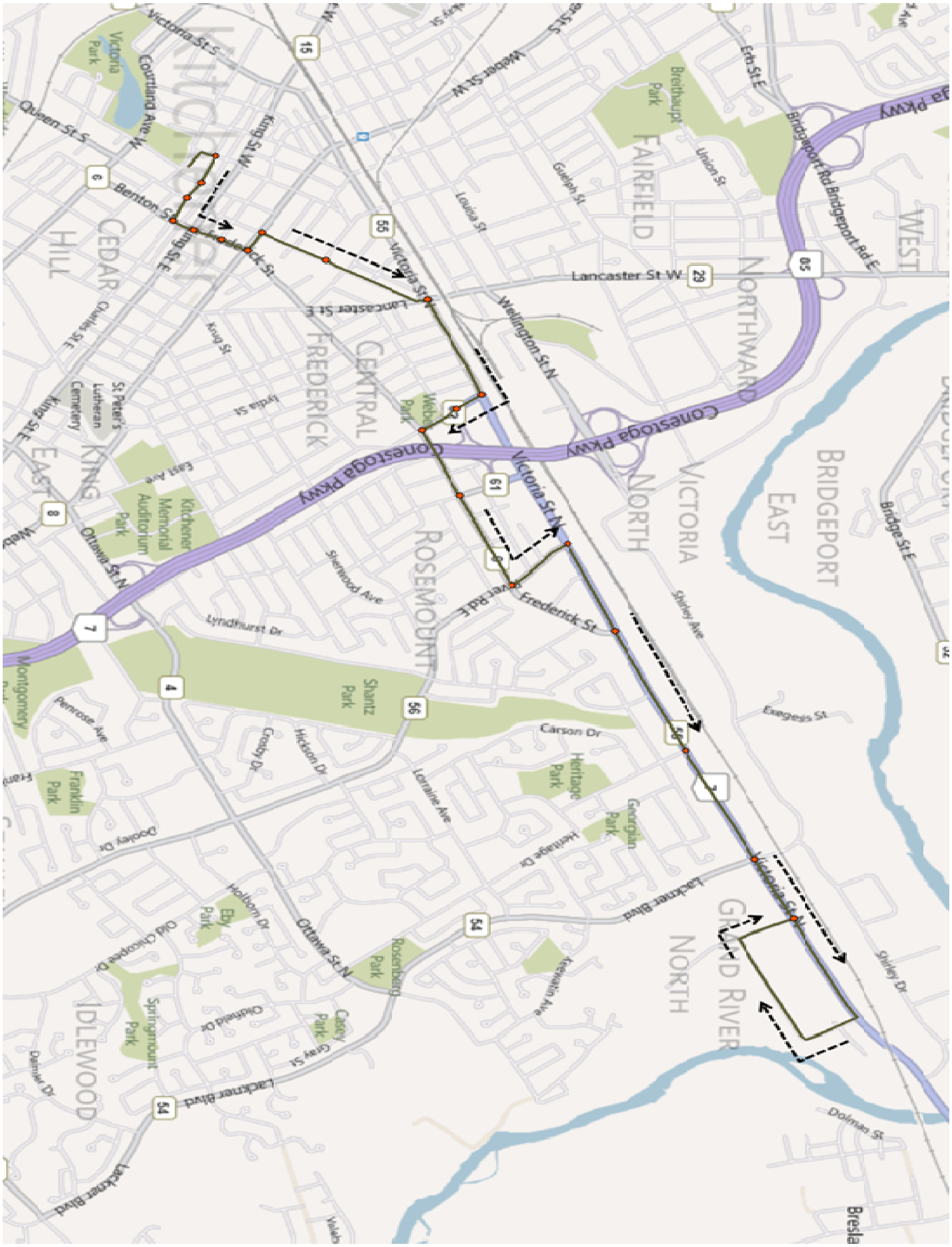
Route 13/Eastbound



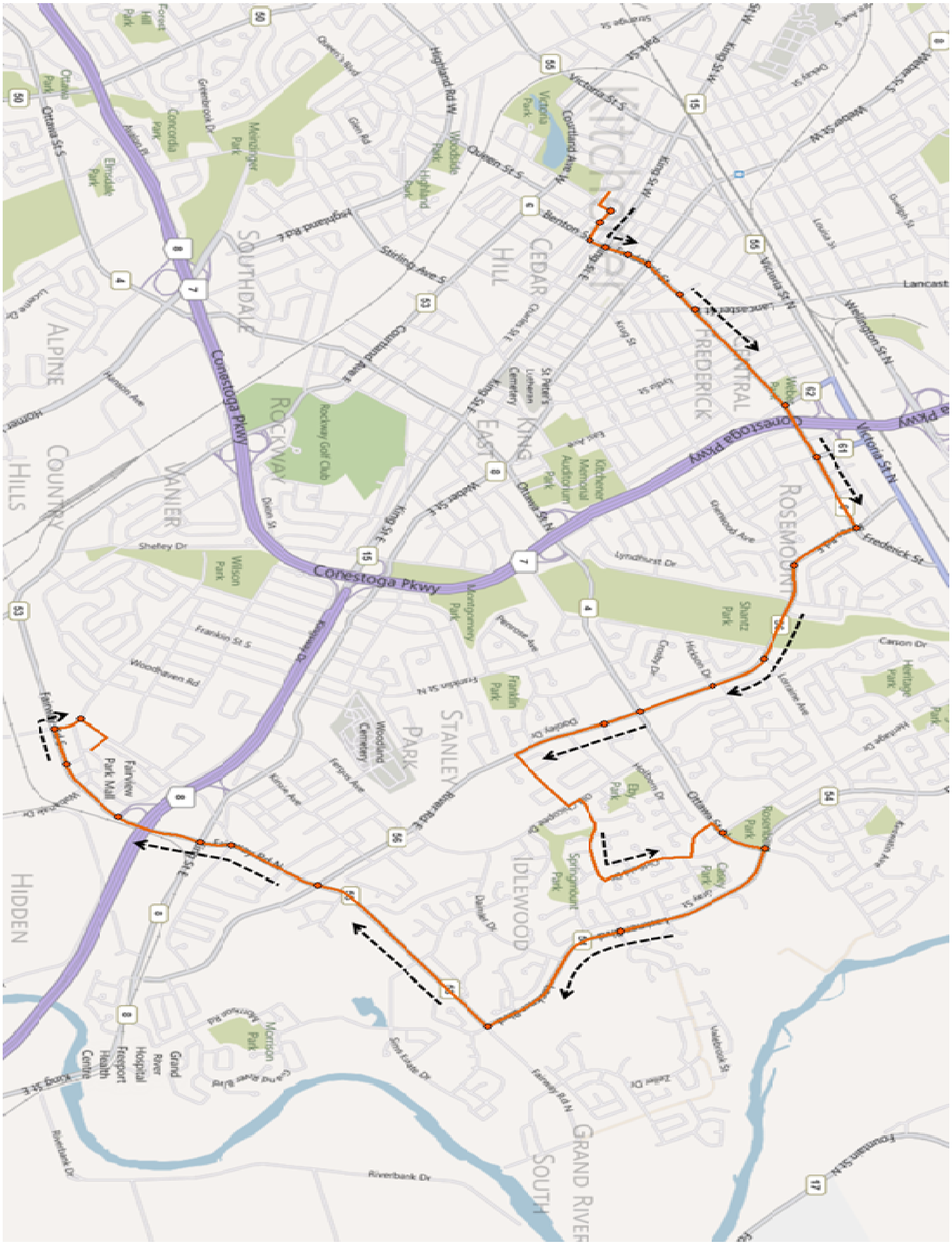
Route 13/Westbound



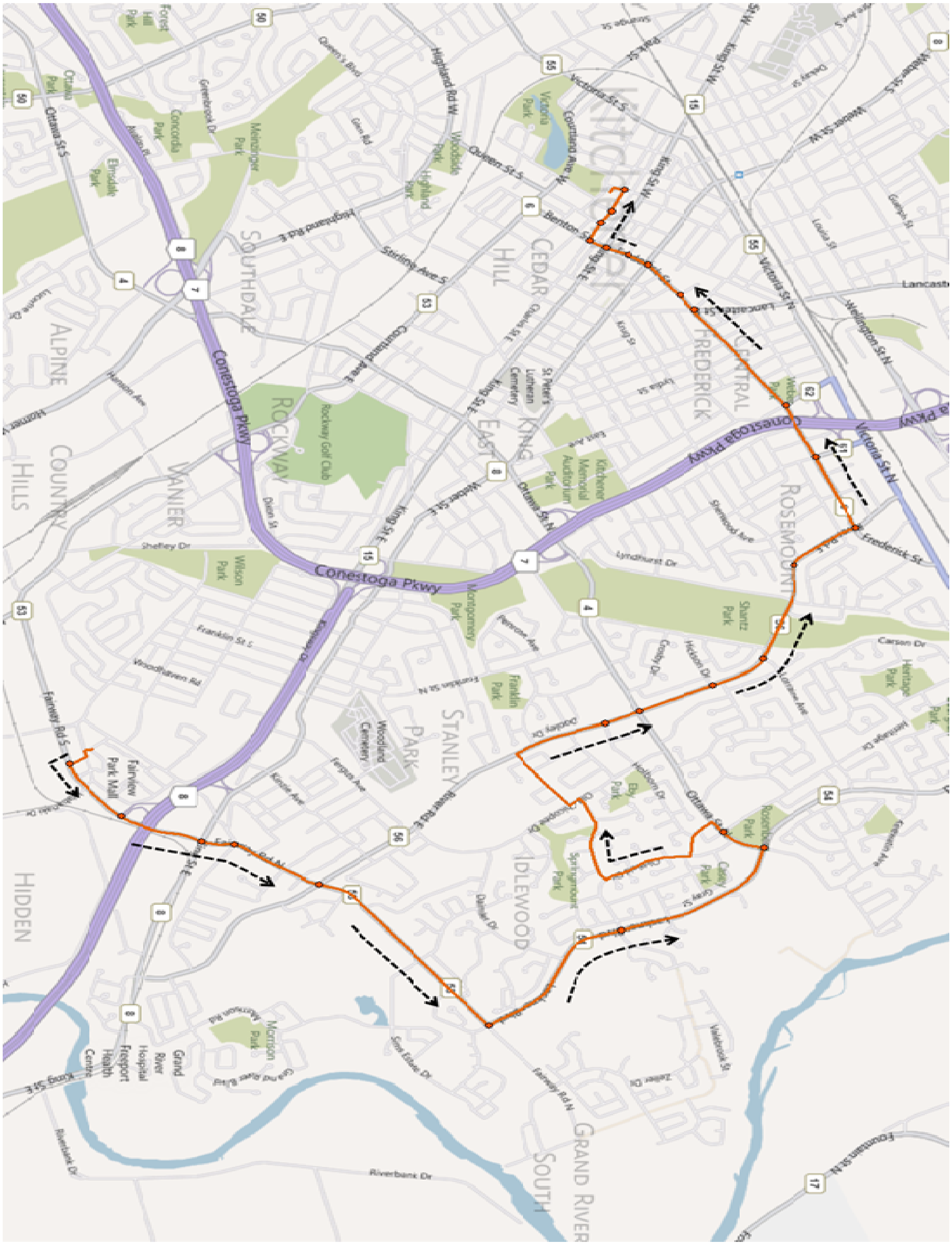
Route 15/Inbound



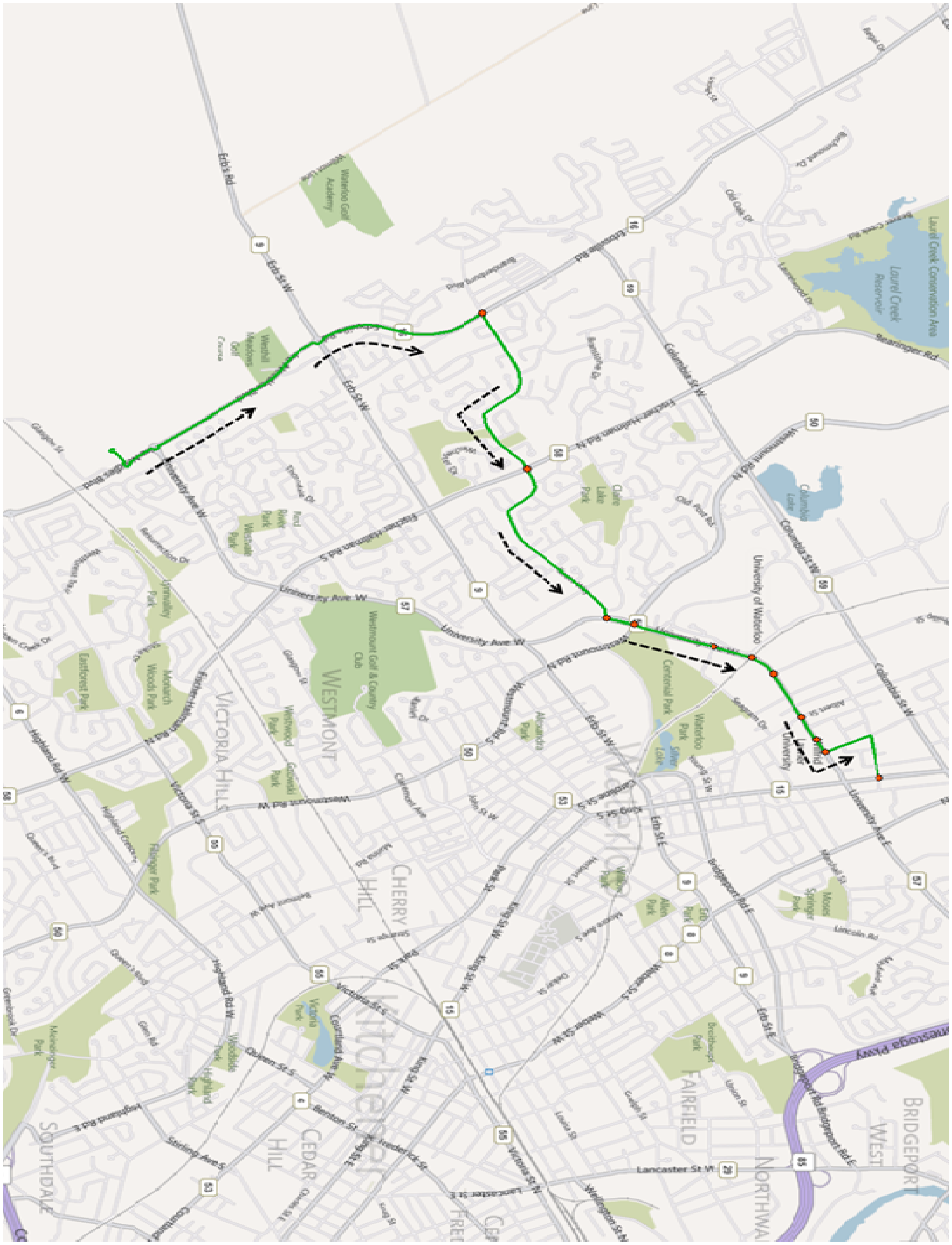
Route 15/Outbound



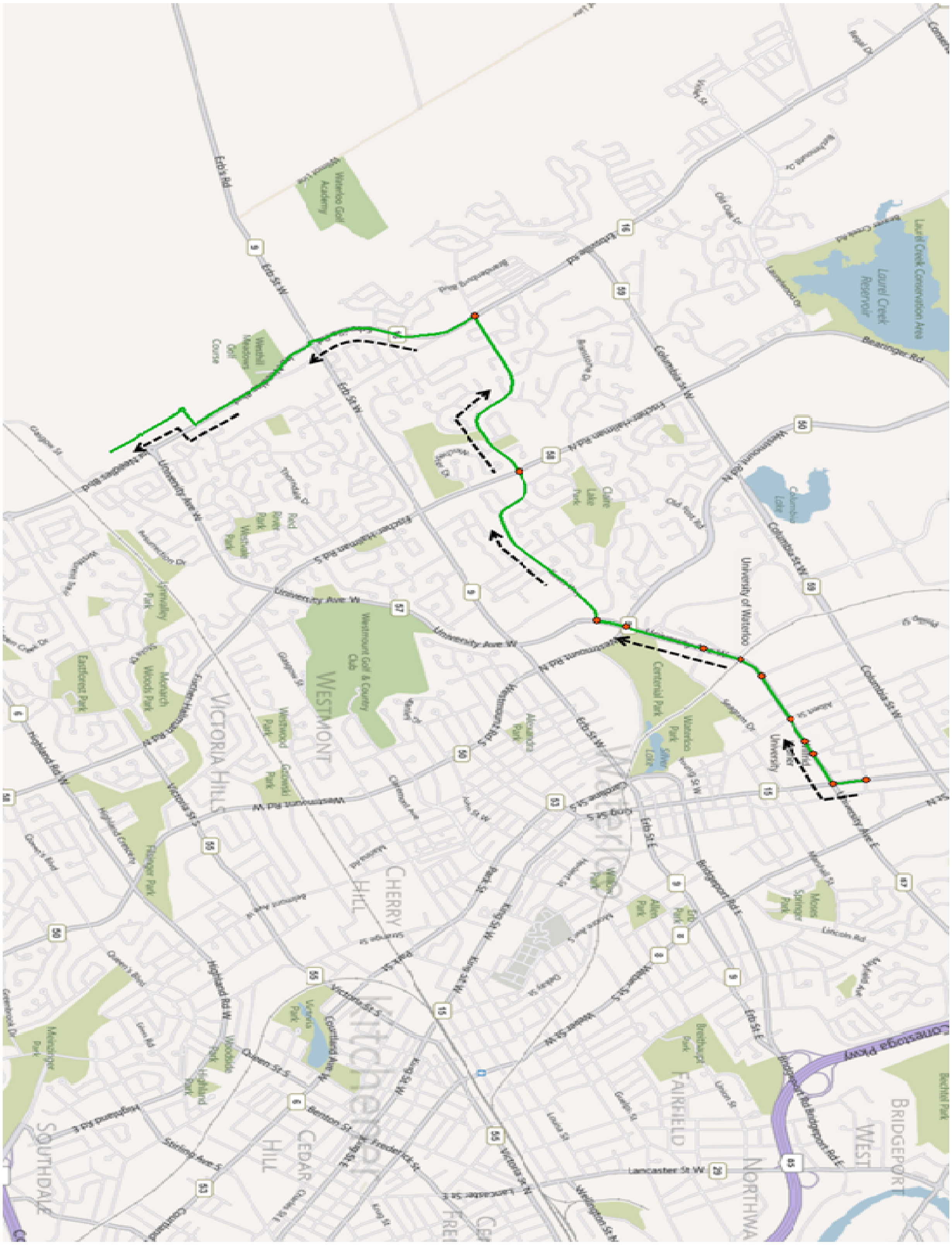
Route 23/Down



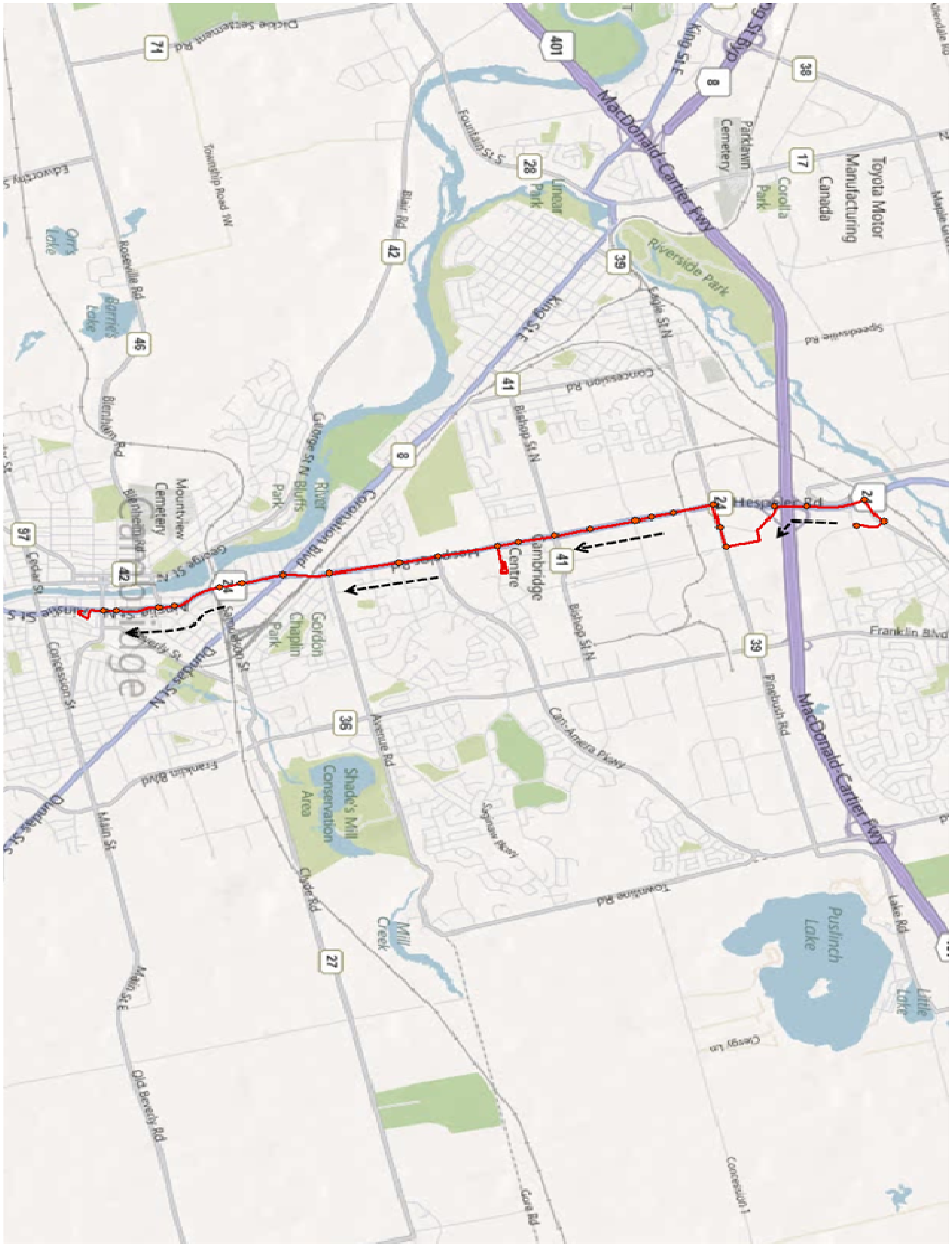
Route 23/Up



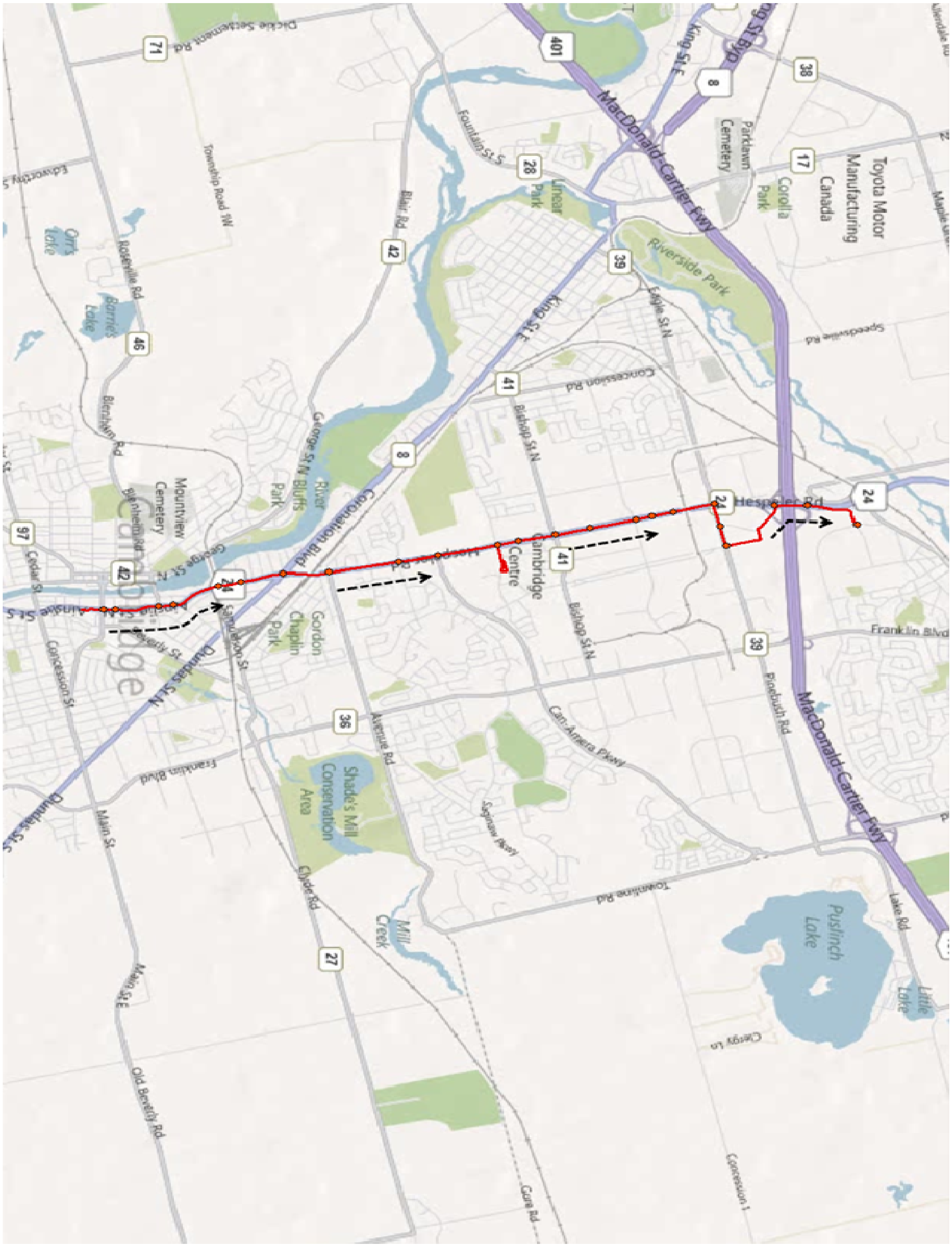
Route 29/Eastbound



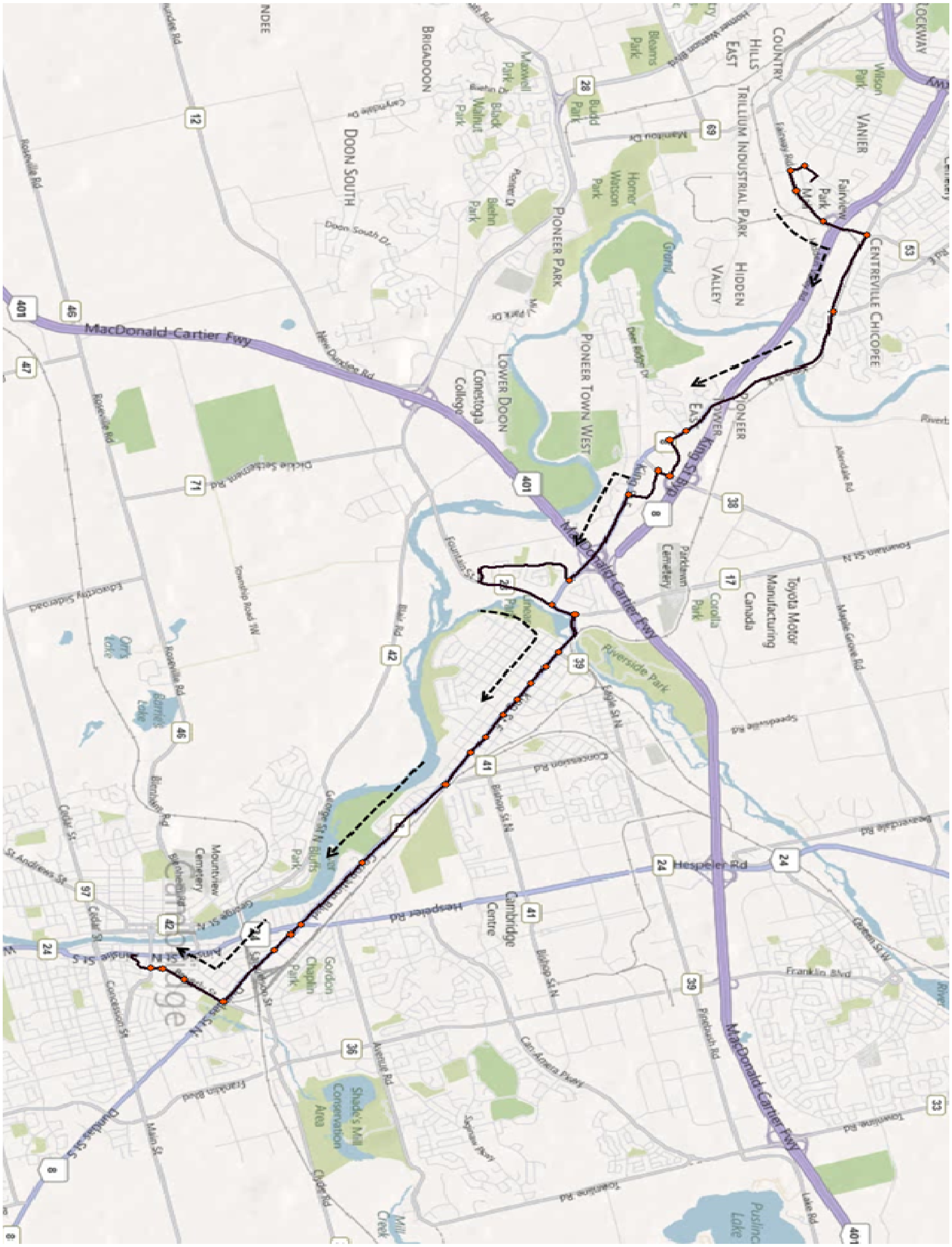
Route 29/Westbound



Route 51/Down

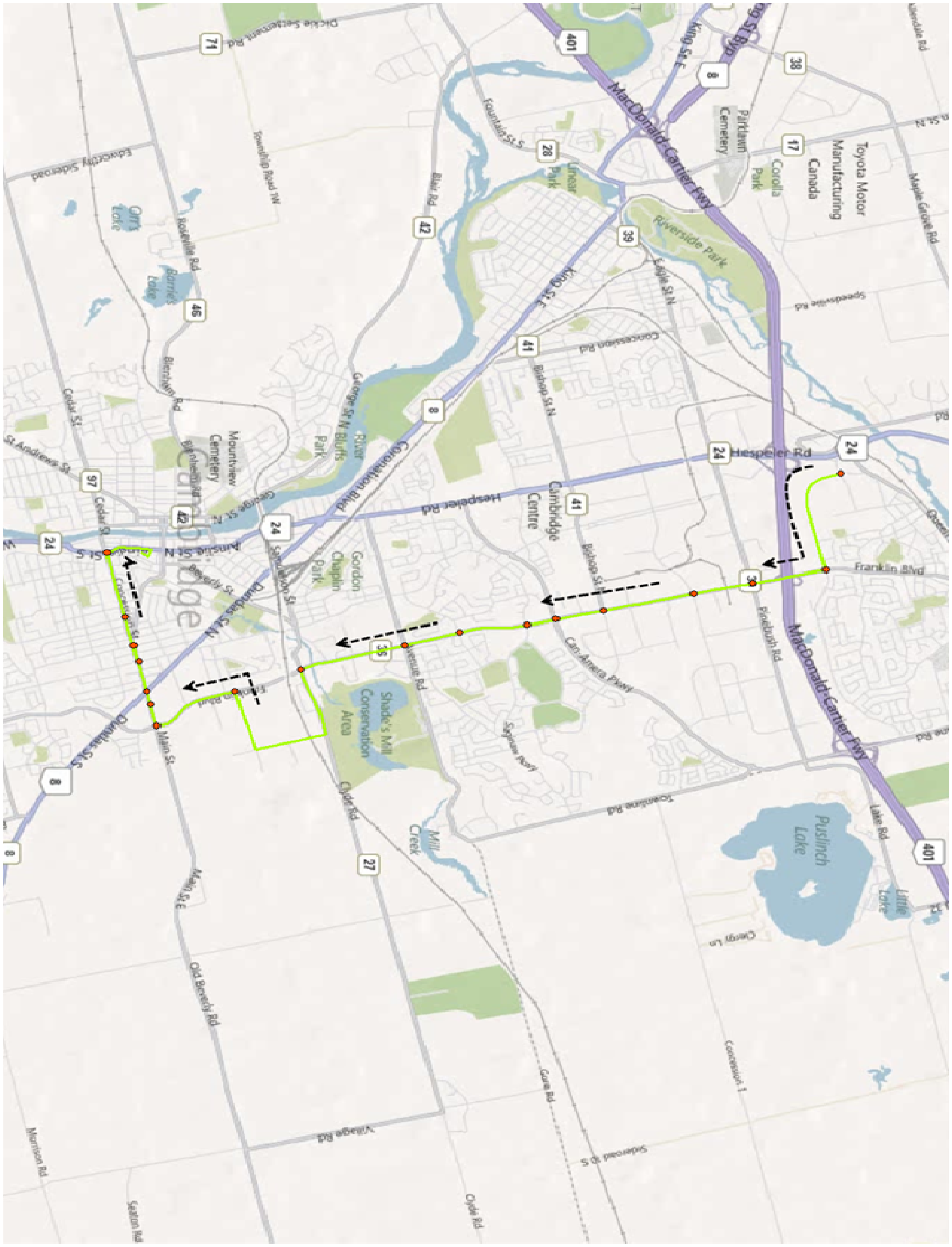


Route 51/Up

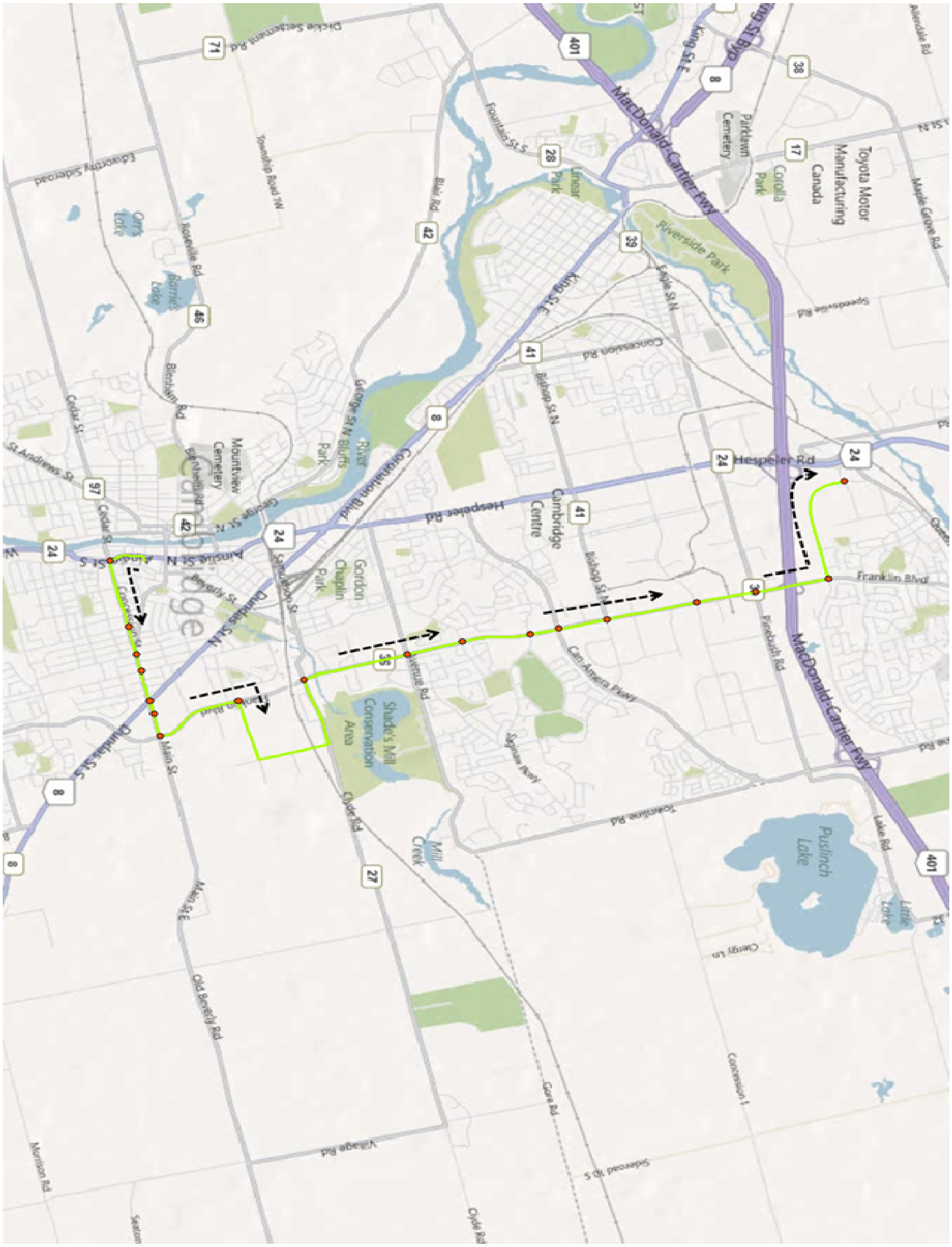


Route 52/Down

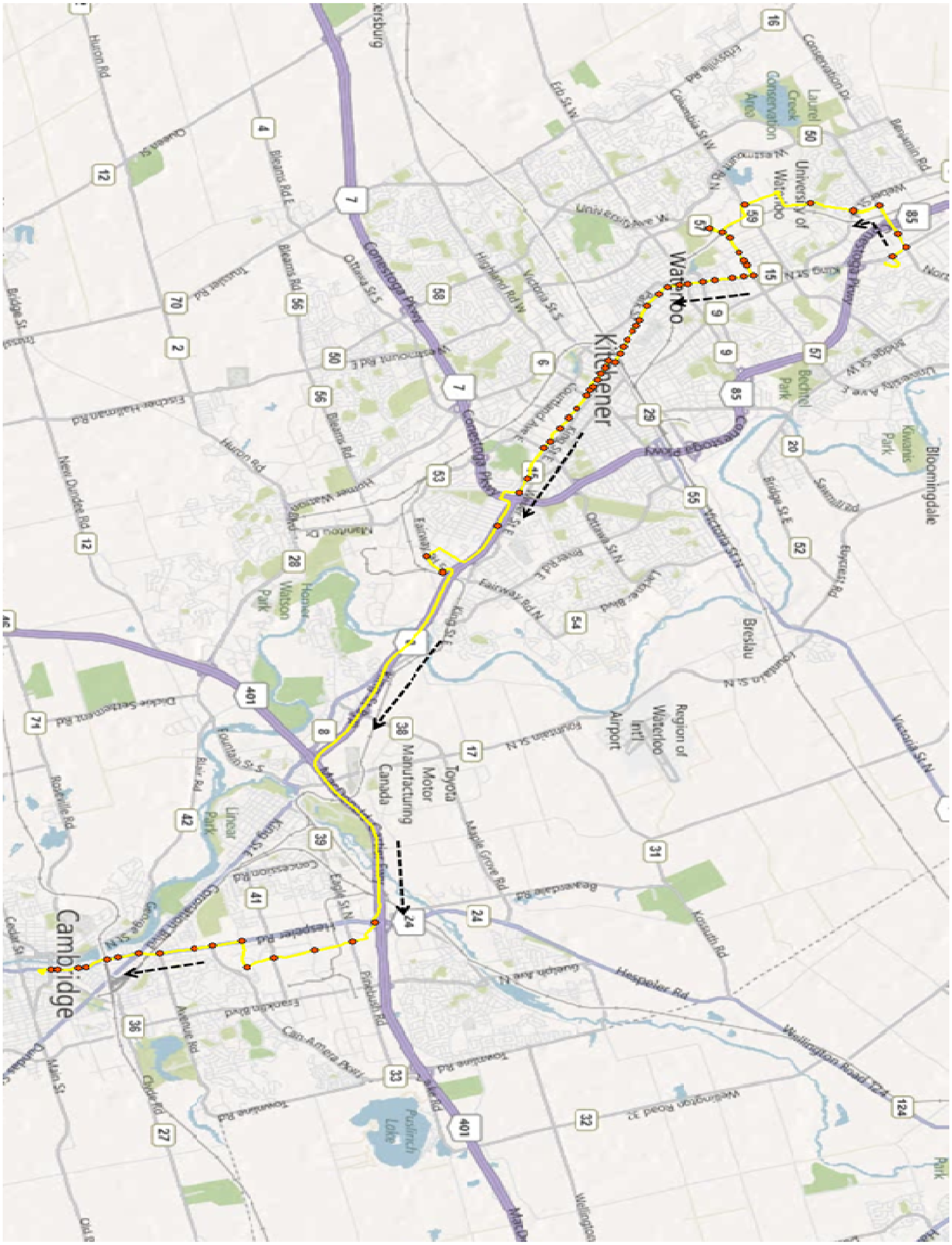
Route 52/Up



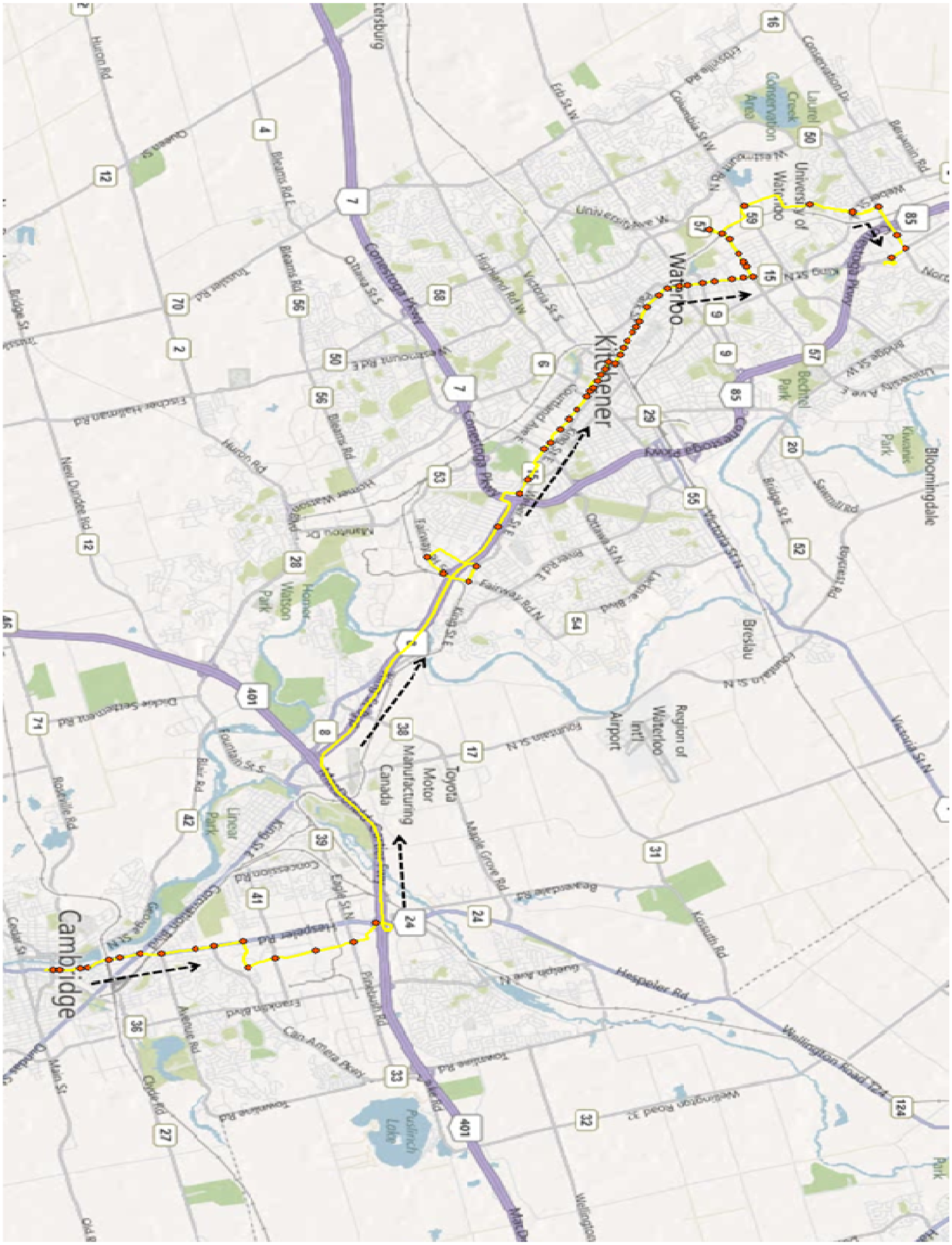
Route 53/Inbound



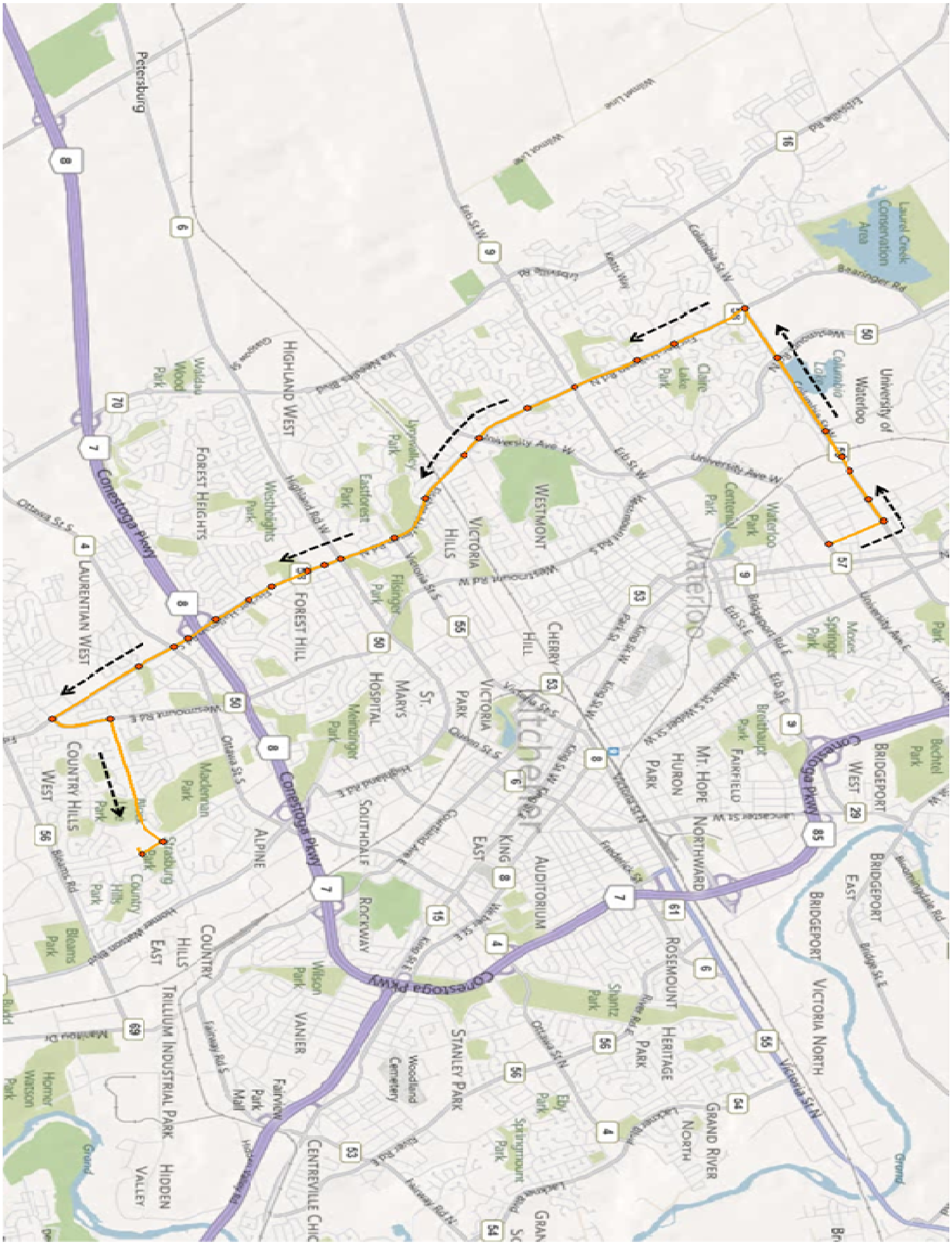
Route 53/Outbound



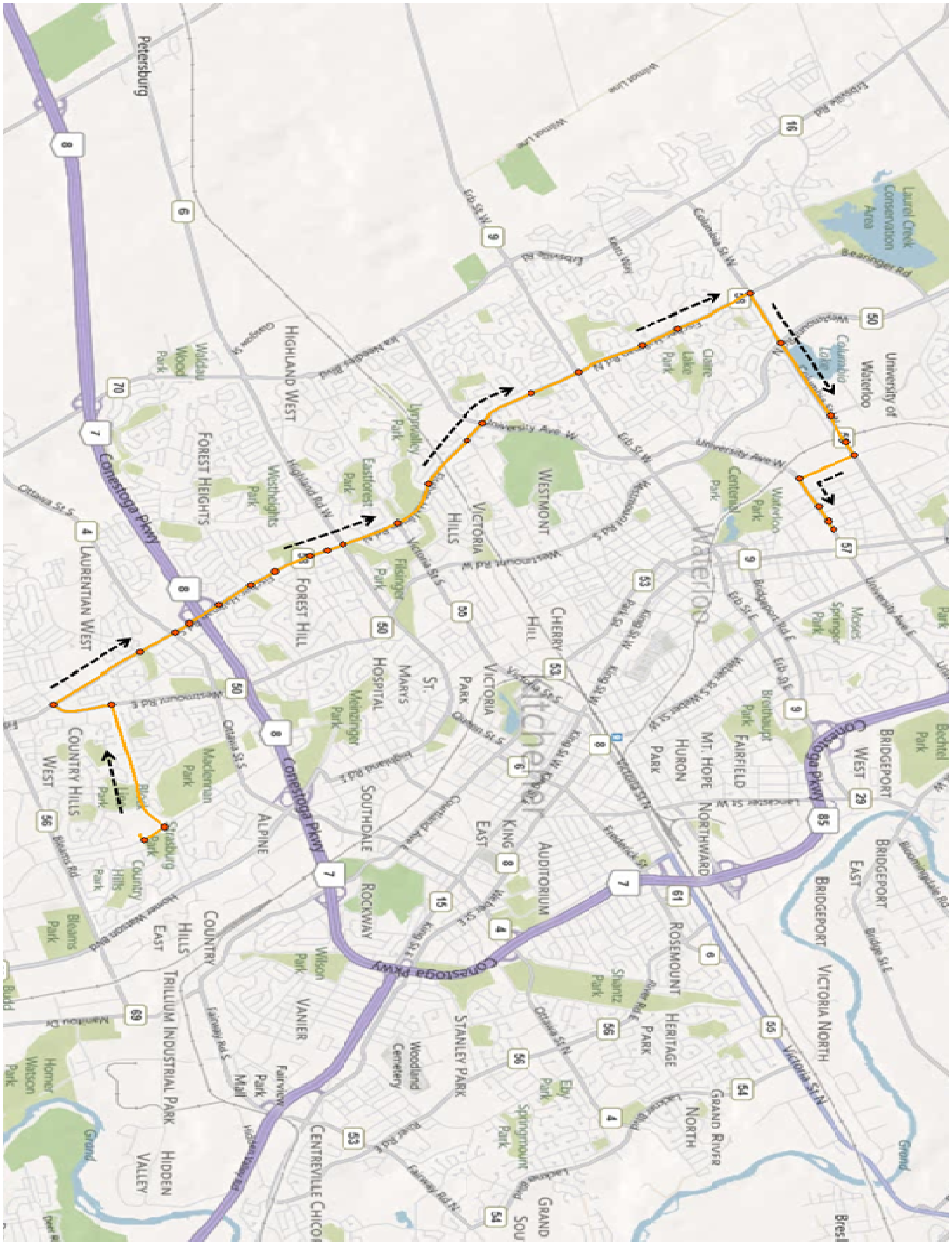
Route 200 (*iXpress*)/Downward



Route 200 (*iXpress*)/Upward



Route 201 (*iXpress*)/Downward



Route 201 (*iXpress*)/Upward

Appendix H. Intersection ranking list on the basis of proposed index

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Stats based on all service trips: Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Based only on stopped delays: Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Dn	HESPELER@Eagle/Pinebush	39.0	43.5	1.1	101	58%	42%	446	102	44	130.04	280	87%	1
11	IB	OTTAWA@Homer Watson	39.1	24.0	0.6	64	85%	15%	252	189	117	87.97	268	85%	2
10	up	HOMER WATSON@Manitou& Doon Village	34.4	25.2	0.7	69.4	81%	19%	217	91	30	91.28	201	81%	3
15	ib	VICTORIA@Natchez	31.7	28.1	0.9	72.7	77%	23%	214	76	15	100.05	234	79%	4
53	IB	FRANKLIN@Savage	31.1	27.4	0.9	71	79%	21%	221	76	30	95.09	310	78%	5
9	DN	NORTHFIELD@Kraus	29.6	27.6	0.9	69.4	75%	25%	164	76	15	111.04	190	75%	6
23	Up	FAIRWAY@Fairview Park Mall	30.8	30.6	1.0	75	65%	35%	222	131	58	98.76	255	74%	7
10	down	FAIRWAY@Wilson	32.1	28.1	0.9	64.7	71%	29%	214	120	30	84.35	258	74%	8
201	dn	FISCHER HALLMAN@Greenbrook/Hwy 7&8 WB Rmp	33.4	36.2	1.1	82	52%	48%	319	152	91	115.73	445	74%	9
10	down	HOMER WATSON@Manitou& Doon Village	28.6	27.3	1.0	68	73%	27%	214	197	61	76.58	264	73%	10
9	UP	NORTHFIELD@Skylark	31.1	27.5	0.9	65	69%	31%	231	76	15	89	189	73%	11
29	EB	UNIVERSITY@Keatsway	27.5	26.2	1.0	66.8	71%	29%	263	106	30	91.37	207	71%	12
10	down	HOMER WATSON@Pioneer	25.6	22.3	0.9	58	80%	20%	214	91	30	79.32	179	70%	13
13	EB	WESTMOUNT@Columbia	26.8	21.4	0.8	56.6	74%	26%	235	91	45	69.44	185	68%	14
200	up	PINEBUSH@Conestoga	26.0	30.9	1.2	77	55%	45%	600	91	30	114	463	67%	15

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Up	HESPELER/WATER@ Coronation/Dundas	25.7	29.3	1.1	72.8	58%	42%	453	151	60	91	336	67%	16
12	Up	HOMER WATSON@Bleams	25.9	26.3	1.0	64.7	64%	36%	214	167	45	81.44	177	66%	17
13	WB	FISCHER HALLMAN@Columbi a	25.7	19.4	0.8	51.1	76%	24%	230	273	0	73	250	66%	18
201	dn	FISCHER HALLMAN@Universit y	23.6	23.1	1.0	63	69%	31%	319	89	44	72	226	66%	19
201	up	UNIVERSITY@Phillip	23.8	25.2	1.1	63	68%	32%	314	121	15	92.92	275	65%	20
9	DN	NORTHFIELD@Highp oint	23.5	22.2	0.9	57	68%	32%	164	76	15	78	146	63%	21
12	Up	OTTAWA@Westmoun t	23.9	26.1	1.1	65	60%	40%	214	73	29	75.5	139	63%	22
9	UP	NORTHFIELD@Highp oint	22.1	21.7	1.0	54	68%	32%	231	61	15	83.4	245	61%	23
51	Dn	QUEEN@Goebel	23.1	21.9	0.9	53	66%	34%	446	164	15	74.56	389	61%	24
15	ib	VICTORIA@Edna	19.5	10.9	0.6	33	93%	7%	214	94	16	56.45	213	61%	25
201	up	ERB@Fischer Hallman	22.0	21.9	1.0	55	65%	35%	314	75	15	74.2	231	60%	26
23	Down	CHARLES@Ontario	21.1	22.3	1.1	54.2	62%	38%	219	76	0	104.4	215	58%	27
200	dn	KING@Northfield	21.5	22.8	1.1	55	60%	40%	658	90	15	80.82	632	58%	28
200	up	CONESTOGA@Dunba r&Lena	19.6	20.0	1.0	50	66%	34%	600	61	0	85.84	889	57%	29
51	Dn	HESPELER@Beaverda le/Queen	19.1	20.0	1.0	50	67%	33%	446	209	0	76.53	320	57%	30
51	Dn	HESPELER/WATER@ Coronation/Dundas	21.4	33.5	1.6	80	32%	68%	446	135	90	92	579	56%	31
12	Dn	HOMER WATSON@Bleams	20.3	24.6	1.2	60	52%	48%	356	75	30	78	208	56%	32

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
53	OB	FRANKLIN@Main	21.0	20.3	1.0	50	59%	41%	225	104	15	77.5	185	56%	33
200	dn	UNIVERSITY@King	19.0	21.9	1.2	53	54%	46%	658	104	45	76.92	479	53%	34
12	Dn	WESTMOUNT@University	16.9	16.7	1.0	42	69%	31%	356	106	15	66.26	334	53%	35
15	ib	VICTORIA@Lancaster	16.4	14.7	0.9	38.7	73%	27%	214	61	15	52.68	177	53%	36
15	ib	WEBER@Queen	18.0	21.4	1.2	51.4	57%	43%	214	76	31	72.29	159	53%	37
200	dn	KING@Bridgeport	17.8	16.2	0.9	40	68%	32%	658	138	15	55.36	504	53%	38
53	OB	DUNDAS@Main	17.6	20.9	1.2	51.6	55%	45%	225	90	30	70.85	131	52%	39
201	dn	FISCHER HALLMAN@Hwy 7&8 EB Ramp	19.4	26.4	1.4	61.2	41%	59%	319	177	44	107.07	271	52%	40
53	IB	FRANKLIN@Pinebush	18.0	23.9	1.3	55	49%	51%	221	121	45	77.7	229	51%	41
201	dn	FISCHER HALLMAN@Queens	18.0	20.4	1.1	48	55%	45%	319	120	30	65	213	51%	42
201	up	WESTMOUNT@Blockline	17.8	18.7	1.1	45	57%	43%	314	61	15	66.68	397	51%	43
10	down	MANITOU@Wabanaki	16.8	18.5	1.1	43.7	61%	39%	214	182	45	58.8	176	51%	44
23	Up	OTTAWA@River	17.0	21.1	1.2	51	53%	47%	222	74	15	71.26	137	51%	45
9	DN	KING@Northfield	13.2	7.2	0.5	21	90%	10%	164	122	0	51.5	222	50%	46
200	up	HESPELER/WATER@Coronation/Dundas	17.1	26.0	1.5	64	40%	60%	600	253	45	91	290	50%	47
9	UP	UNIVERSITY@Phillip	16.0	14.9	0.9	38	66%	34%	231	72	14	50.8	161	50%	48
200	dn	HESPELER/WATER@Coronation/Dundas	17.0	26.6	1.6	65	38%	62%	658	136	30	88.82	388	50%	49
200	dn	UNIVERSITY@Seagram	15.3	18.1	1.2	45	60%	40%	658	76	15	62.17	725	50%	50
23	Up	FAIRWAY@King	17.0	20.0	1.2	47.8	53%	47%	222	136	45	72.4	173	49%	51
51	Dn	HESPELER@Bishop	17.5	21.2	1.2	51	49%	51%	446	139	15	82.8	244	49%	52

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
9	UP	WEBER@Parkside	18.1	19.7	1.1	46	52%	48%	231	76	0	78.46	201	49%	53
9	UP	UNIVERSITY@Albert	15.8	15.8	1.0	39	64%	36%	231	119	15	59.5	187	49%	54
9	UP	UNIVERSITY@Seagram	14.9	18.3	1.2	45	58%	42%	231	76	15	64.5	163	48%	55
10	down	WILSON@Kingsway	13.6	13.5	1.0	33.7	69%	31%	214	74	0	99.96	370	47%	56
200	up	BISHOP@Conestoga	17.8	17.5	1.0	39	53%	47%	600	91	15	44	837	47%	57
13	WB	COLUMBIA@Hagey& University Of Waterloo	14.3	15.2	1.1	37	63%	37%	230	76	30	49	181	47%	58
12	Dn	MANITOU@Bleams	14.6	16.3	1.1	40.5	58%	42%	356	136	61	57.61	284	47%	59
12	Dn	WESTMOUNT@Victoria	15.4	20.8	1.4	51	47%	53%	356	90	15	68	183	47%	60
201	dn	COLUMBIA@Hazel	14.2	16.2	1.1	38	57%	43%	319	61	15	64	282	45%	61
1	ib	WEBER@Cedar&Krug	13.4	16.2	1.2	39	58%	42%	336	106	30	54.52	336	45%	62
200	dn	HESPELER@Dunbar	14.4	20.6	1.4	49	46%	54%	658	91	30	78	363	45%	63
201	up	FISCHER HALLMAN@Greenbrook/Hwy 7&8 WB Rmp	13.6	15.7	1.2	37.7	56%	44%	314	105	30	57.8	197	44%	64
201	dn	FISCHER HALLMAN@Victoria	15.1	20.1	1.3	45.2	46%	54%	319	163	30	67.79	171	44%	65
23	Down	FREDERICK@Lancaster	13.7	15.2	1.1	38	55%	45%	219	100	29	43.45	130	44%	66
15	ob	WEBER@Frederick	13.5	17.7	1.3	39.3	53%	47%	218	87	15	80	141	43%	67
23	Up	FREDERICK@River	12.0	14.4	1.2	35	58%	42%	222	59	0	71.56	153	43%	68
53	OB	FRANKLIN@Jamieson/Holiday Inn	11.8	14.7	1.2	36.6	56%	44%	225	61	15	67.03	182	42%	69
12	Up	WEBER@University	14.6	22.6	1.5	53.7	33%	67%	214	74	30	68.4	135	42%	70
53	OB	FRANKLIN@Can Amera	12.3	14.1	1.1	33.6	56%	44%	225	107	30	48.79	165	42%	71

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
201	dn	FISCHER HALLMAN@Westmount&Max Becker	12.4	15.1	1.2	35.2	54%	46%	319	89	0	76.64	286	42%	72
1	ob	QUEEN@Charles	14.9	17.9	1.2	40	44%	56%	330	91	46	55.3	180	42%	73
200	up	CHARLES@Gaukel	12.7	15.9	1.3	37	51%	49%	600	74	29	53	494	41%	74
11	OB	OTTAWA@Alpine	11.3	14.8	1.3	36.3	54%	46%	248	60	15	69.4	182	41%	75
12	Dn	WESTMOUNT@Erb	10.9	15.0	1.4	37	54%	46%	356	167	0	64.01	266	41%	76
12	Up	UNIVERSITY@Seagram	11.8	15.6	1.3	39	49%	51%	214	76	15	55.7	157	41%	77
15	ob	FREDERICK@Edna	10.8	15.4	1.4	36.3	51%	49%	218	75	15	66.12	129	40%	78
201	up	FISCHER HALLMAN@Victoria	9.0	8.7	1.0	22	68%	32%	314	91	0	64	227	40%	79
11	IB	KING@Stirling	14.0	22.3	1.6	51	29%	71%	252	88	15	66.64	84	39%	80
51	Up	HESPELER@Munch	11.7	17.1	1.5	41	43%	57%	453	121	30	62	263	39%	81
201	up	WESTMOUNT@Columbia	11.6	18.4	1.6	45	39%	61%	314	121	30	67.9	221	39%	82
201	up	FISCHER HALLMAN@University	11.9	16.8	1.4	41.4	41%	59%	314	63	31	63.76	138	39%	83
52	Dn	KING@Deer Ridge Centre&Sportsworld Crossing	10.1	13.9	1.4	33	52%	48%	372	61	0	93.92	301	38%	84
200	up	QUEEN@Charles	11.8	14.7	1.2	36	44%	56%	600	91	46	42	309	38%	85
51	Up	HESPELER@Bishop	9.5	15.3	1.6	38.8	47%	53%	453	175	29	67.6	230	38%	86
53	OB	FRANKLIN@Avenue	9.5	11.3	1.2	28	56%	44%	225	121	0	47.4	142	38%	87
9	DN	UNIVERSITY@Phillip	11.8	18.2	1.5	42.7	37%	63%	164	75	15	58.41	75	37%	88
200	dn	SHELDON@Conestoga	10.5	14.9	1.4	36	45%	55%	658	91	15	57.29	358	37%	89
12	Dn	STRASBURG@Bleams	9.6	12.5	1.3	29	52%	48%	356	61	15	57	300	36%	90
15	ob	CHARLES@Ontario	10.7	15.4	1.4	37.3	41%	59%	218	62	0	83.82	245	36%	91

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
53	IB	CONCESSION/MAIN @Chalmers	11.2	14.9	1.3	35	42%	58%	221	73	29	46.84	122	36%	92
23	Down	FREDERICK@Edna	9.8	13.0	1.3	32	47%	53%	219	91	15	41	117	36%	93
1	ib	RIVER@Holborn	9.4	11.6	1.2	27	52%	48%	336	64	0	63.85	193	36%	94
200	dn	FRANKLIN@Kingswa y	7.9	8.6	1.1	21	60%	40%	658	76	0	42	485	35%	95
15	ib	FREDERICK@Duke	9.4	12.6	1.3	29.7	48%	52%	214	44	0	91.07	126	35%	96
15	ib	EDNA@Hwy 7&8 WB Ramp	9.2	11.8	1.3	28.7	49%	51%	214	87	44	36.88	147	35%	97
200	up	SHELDON@Conestoga	7.1	6.4	0.9	16	65%	36%	600	76	0	41.6	421	35%	98
12	Up	UNIVERSITY@Trans Canada Trail	8.7	11.5	1.3	29	49%	51%	214	76	30	37.62	125	34%	99
200	dn	BEARINGER@Parksid e	8.9	11.6	1.3	28	49%	51%	658	61	15	43	453	34%	100
15	ib	FREDERICK@River	9.7	13.8	1.4	33	42%	58%	214	76	15	43.16	101	34%	101
1	ib	FREDERICK@Duke	9.0	11.8	1.3	27.5	49%	51%	336	59	0	68.24	310	34%	102
200	dn	UNIVERSITY@Phillip	10.3	14.0	1.4	32.3	41%	59%	658	78	16	48.36	289	34%	103
15	ib	VICTORIA@Frederick	8.3	12.1	1.4	28.7	49%	51%	214	45	0	76.1	157	34%	104
15	ob	QUEEN@Charles	11.2	16.5	1.5	38.3	33%	67%	218	74	30	56.71	113	34%	105
15	ob	VICTORIA@Lancaster	7.4	10.5	1.4	26	53%	47%	218	106	0	40.45	231	34%	106
200	dn	WEBER@Parkside	9.0	11.2	1.2	26	49%	51%	658	105	15	41	542	34%	107
12	Dn	WEBER@University	10.3	16.8	1.6	35	37%	63%	356	117	15	70.65	168	34%	108
23	Up	OTTAWA@Lackner	7.9	9.6	1.2	23.9	53%	47%	222	76	15	39.62	143	34%	109

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Dn	HESPELER@Can Amera&YMCA Driveway	9.7	13.8	1.4	33	40%	60%	446	91	15	54.72	280	34%	110
51	Dn	PINEBUSH@Walmart &Home Depot	9.6	16.2	1.7	37	36%	64%	446	118	15	72.76	264	33%	111
201	up	UNIVERSITY@Hazel	8.3	13.9	1.7	34	41%	59%	314	44	0	78.37	189	33%	112
12	Dn	LEXINGTON@Davenport	8.8	14.1	1.6	33.5	38%	62%	356	91	30	53	151	32%	113
1	ib	WEBER@Frederick	7.5	11.9	1.6	26	47%	53%	336	30	0	95.36	204	32%	114
23	Up	FAIRWAY@River	7.5	10.6	1.4	26	47%	53%	222	152	0	47	142	32%	115
12	Up	UNIVERSITY@Albert	9.1	14.5	1.6	32	38%	62%	214	118	15	57.01	100	32%	116
201	dn	COLUMBIA@Rim Driveway	6.9	8.3	1.2	19	53%	47%	319	89	45	28	185	31%	117
13	EB	FISCHER HALLMAN@Laurelwood	7.8	12.4	1.6	29	41%	59%	235	61	15	49.38	155	31%	118
1	ob	CHARLES@Gaukel	8.1	14.6	1.8	26.1	42%	58%	330	43	0	130.34	228	31%	119
15	ob	FREDERICK@Bruce	7.0	8.8	1.3	21	50%	50%	218	76	15	31	123	31%	120
13	WB	WESTMOUNT@Columbia	8.7	15.1	1.7	31.2	36%	64%	230	121	15	65.6	107	31%	121
201	up	UNIVERSITY@Albert	8.9	18.2	2.1	46	21%	79%	314	74	30	60.97	97	30%	122
51	Dn	PINEBUSH@Conestoga	7.4	13.8	1.9	24	44%	56%	446	167	0	82.38	815	30%	123
200	up	CHARLES@Ontario	7.7	16.0	2.1	40	28%	72%	600	63	16	73.14	196	30%	124
200	dn	UNIVERSITY@Albert	7.4	9.8	1.3	23.3	44%	56%	658	91	0	59.94	407	30%	125

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
53	IB	FRANKLIN@Clyde	6.9	10.3	1.5	26	43%	57%	221	45	0	41.75	133	30%	126
51	Up	HESPELER@Sheldon/ Langs	7.9	13.0	1.6	30.8	35%	65%	453	90	15	58.94	188	29%	127
200	up	KING@Northfield	7.8	13.9	1.8	33	33%	67%	600	107	31	53.08	328	29%	128
13	EB	COLUMBIA@Hagey& University Of Waterloo	7.2	11.0	1.5	26	41%	59%	235	106	45	39.72	113	29%	129
52	Dn	SPORTSWORLD@Gat eway	8.1	18.1	2.2	43	23%	77%	372	61	15	71.25	100	29%	130
53	IB	FRANKLIN@Avenue	8.1	13.6	1.7	31	33%	67%	221	91	30	50	135	29%	131
9	UP	ALBERT@Hazel/Beari nger	6.3	9.2	1.5	20	47%	53%	231	76	0	48.6	140	29%	132
53	OB	FRANKLIN@Pinebush	7.3	13.6	1.9	26.6	38%	62%	225	206	15	67.72	167	29%	133
1	ob	FREDERICK@Duke	6.1	8.5	1.4	18	49%	51%	330	60	0	59.51	169	29%	134
51	Up	HESPELER@Can Amera&YMCA Driveway	8.1	13.7	1.7	30	33%	67%	453	90	15	55.76	172	29%	135
23	Down	FREDERICK@Duke	5.8	7.8	1.3	18.2	49%	51%	219	45	0	53.9	121	29%	136
15	ob	EDNA@Hwy 7&8 WB Ramp	6.8	9.2	1.4	22	44%	56%	218	60	15	33.88	101	29%	137
200	up	FRANKLIN@Kingswa y	7.4	12.3	1.7	28.1	37%	64%	600	76	30	44.52	520	29%	138
10	down	DOON VILLAGE@Pioneer	6.3	8.8	1.4	21	45%	55%	214	75	0	44.76	139	29%	139
200	up	CHARLES@Stirling	8.5	13.6	1.6	32	30%	70%	600	75	30	40.85	191	29%	140
200	up	KING@Wellington	7.7	12.7	1.7	31	33%	67%	600	67	17	44.79	226	29%	141

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
23	Down	FAIRWAY@Fairview Park Mall	7.8	15.1	1.9	31	32%	68%	219	135	30	73.02	93	29%	142
12	Up	STRASBURG@Blockline	6.6	10.2	1.5	19.7	45%	55%	214	199	15	51.3	184	28%	143
29	EB	UNIVERSITY@Hazel	5.6	9.9	1.8	23	44%	56%	263	45	0	58.72	147	28%	144
29	WB	UNIVERSITY@Phillip	7.9	14.5	1.8	33.3	29%	71%	268	61	15	58.31	134	28%	145
9	DN	UNIVERSITY@Albert	6.7	10.2	1.5	24.7	40%	60%	164	70	0	50.29	92	28%	146
15	ob	FREDERICK@Duke	5.8	7.6	1.3	18	47%	53%	218	95	0	33	128	28%	147
29	EB	UNIVERSITY@Trans Canada Trail	5.9	9.1	1.5	22	43%	57%	263	89	30	36.08	144	28%	148
53	OB	FRANKLIN@Elgin/Saginaw	7.6	14.9	2.0	32.2	30%	70%	225	182	0	64.62	85	28%	149
11	OB	CHARLES@Benton	7.3	10.8	1.5	26	36%	64%	248	74	30	32.59	107	28%	150
51	Up	AINSLIE@Simcoe&Market	5.8	7.9	1.4	19	45%	55%	453	70	14	27.24	222	27%	151
51	Up	AINSIE@Parkhill	6.8	12.2	1.8	29	33%	67%	453	61	15	43.89	251	27%	152
23	Up	QUEEN@Charles	6.9	11.8	1.7	27.9	33%	67%	222	90	0	49.93	128	27%	153
1	ib	OTTAWA@River	8.7	17.5	2.0	26.5	30%	70%	336	73	15	75.32	201	27%	154
1	ob	WEBER@Cedar&Krug	5.8	11.1	1.9	20.1	42%	58%	330	180	45	55.4	155	27%	155
29	WB	UNIVERSITY@Albert	7.1	13.8	1.9	34	26%	74%	268	89	30	53.24	81	27%	156
9	DN	ALBERT@Hazel/Bearinger	5.5	8.8	1.6	18	45%	55%	164	61	0	52	103	27%	157

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
12	Up	COURTLAND&FAIRWAY@Manitou	5.9	9.3	1.6	20	42%	58%	214	92	0	61.79	273	27%	158
201	up	FISCHER HALLMAN@Westmount&Max Becker	6.3	12.0	1.9	28	33%	67%	314	61	0	104.56	175	27%	159
1	ob	CHARLES@Ontario	7.1	11.6	1.6	28	31%	69%	330	58	0	57.67	381	27%	160
12	Dn	UNIVERSITY@Phillip	7.2	14.2	2.0	33.5	26%	74%	356	59	15	58.45	158	26%	161
15	ob	CHARLES@Gaukel	6.0	11.2	1.8	23	38%	62%	218	43	0	84.13	133	26%	162
201	up	FISCHER HALLMAN@Queens	6.6	12.0	1.8	28	32%	68%	314	108	0	57.24	141	26%	163
200	up	OTTAWA@Charles	6.9	12.5	1.8	31	28%	72%	600	61	0	55	351	26%	164
201	dn	FISCHER HALLMAN@Glasgow	6.3	10.8	1.7	26	34%	66%	319	92	15	41.56	123	26%	165
200	dn	CHARLES@Water	4.8	6.7	1.4	13	49%	51%	658	74	0	41.11	435	26%	166
12	Dn	UNIVERSITY@Lincoln	6.7	12.5	1.9	29	30%	70%	356	76	0	75.92	205	26%	167
200	dn	NORTHFIELD@Parkside	5.7	9.7	1.7	20	40%	60%	658	61	0	58.24	526	26%	168
201	dn	FISCHER HALLMAN@Ottawa	6.0	10.7	1.8	20	39%	61%	319	109	0	86.79	147	26%	169
200	up	KING@Erb	6.0	10.1	1.7	24	35%	65%	600	76	15	39	281	26%	170
200	up	KING@Conestoga Mall	5.2	9.0	1.7	20	40%	60%	600	79	16	52.45	285	26%	171
29	EB	UNIVERSITY@Albert	6.1	11.2	1.8	22.8	35%	65%	263	118	0	57.65	132	25%	172
53	IB	FRANKLIN@Bishop	6.6	14.7	2.2	36	21%	79%	221	91	0	77.4	211	25%	173
200	dn	FAIRWAY@Hwy 8 EB Ramp	5.5	9.7	1.8	21	37%	63%	658	60	0	63.52	371	25%	174

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
201	dn	WESTMOUNT@Columbia	6.6	13.1	2.0	26	30%	70%	319	167	15	60.56	120	25%	175
53	OB	FRANKLIN@Clyde	5.8	10.1	1.7	21.6	36%	64%	225	91	30	42.68	265	25%	176
200	up	CHARLES@Benton	5.5	9.3	1.7	23	35%	66%	600	89	30	37.04	250	25%	177
201	dn	FISCHER HALLMAN@Highland Hills Mall	5.5	10.3	1.9	23	34%	66%	319	135	75	50.44	124	25%	178
201	up	STRASBURG@Blockline	4.5	6.9	1.5	16	43%	57%	314	31	0	59	258	25%	179
51	Up	HESPELER@Eagle/Pinebush	5.4	9.6	1.8	21	36%	64%	453	75	0	66.64	342	24%	180
51	Up	AINSLIE@Main	5.4	9.3	1.7	20.8	36%	64%	453	87	29	37	334	24%	181
51	Dn	AINSIE@Parkhill	6.0	12.5	2.1	32	24%	76%	446	73	15	48.3	115	24%	182
51	Dn	HIGHWAY 24@Hwy 401 WB Ramp	5.8	9.4	1.6	20.5	35%	65%	446	76	15	38.88	215	24%	183
200	dn	HESPELER@Can Amera&YMCA Driveway	6.4	12.5	2.0	28.3	26%	74%	658	91	30	52.4	342	24%	184
12	Dn	UNIVERSITY@Albert	6.4	13.3	2.1	30.5	24%	76%	356	88	29	53	96	24%	185
23	Up	WEBER@Frederick	6.1	12.4	2.0	24	30%	70%	222	59	15	51.87	77	24%	186
12	Up	MANITOU@Bleams	5.2	9.3	1.8	21	35%	65%	214	136	61	40.08	199	24%	187
53	IB	FRANKLIN@Elgin/Saginaw	6.6	14.4	2.2	34	19%	81%	221	104	15	58.94	63	24%	188
200	up	NORTHFIELD@Parkside	5.1	9.9	1.9	22.1	33%	67%	600	60	0	56.24	277	24%	189

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Up	AINSLIE@Dickson	6.0	9.5	1.6	22	30%	70%	453	73	29	30	155	23%	190
23	Up	CHARLES@Gaukel	4.2	7.0	1.7	14	41%	59%	222	43	0	56.33	110	23%	191
200	up	KING@Willis Way	5.6	9.7	1.7	23	30%	70%	600	61	0	46.42	212	23%	192
12	Dn	WESTMOUNT@Glasgow	5.9	12.3	2.1	30	21%	79%	356	91	30	44.76	253	23%	193
9	UP	WEBER@Albert	4.9	9.0	1.8	20	33%	67%	231	91	0	45	107	23%	194
12	Dn	WESTMOUNT@Blockline	3.5	5.4	1.6	12	43%	57%	356	77	0	31	173	22%	195
51	Dn	HESPELER@Sheldon/Langs	5.6	12.0	2.1	28	23%	77%	446	92	31	50.32	108	22%	196
11	IB	KING@Benton/Frederick	5.5	11.8	2.1	25	26%	74%	252	88	0	69	110	22%	197
11	OB	STRASBURG@Forest Glen Plaza	4.5	7.5	1.7	16	36%	64%	248	61	0	43.9	404	22%	198
200	dn	AINSIE@Parkhill	5.7	11.1	1.9	27	23%	77%	658	77	15	42.6	176	22%	199
200	dn	KING@William	5.2	9.5	1.8	23	28%	72%	658	60	0	41	257	22%	200
11	IB	KING@Queen	5.6	12.3	2.2	30.9	19%	81%	252	75	30	52.85	83	22%	201
23	Down	FAIRWAY@Hwy 8 EB Ramp	5.8	14.6	2.5	34.6	15%	85%	219	88	44	64.43	37	22%	202
23	Up	FREDERICK@Duke	4.7	9.8	2.1	23.8	27%	73%	222	57	14	47.31	66	22%	203
1	ob	KING@Benton/Frederick	4.0	8.0	2.0	17	35%	65%	330	45	0	66.58	144	22%	204
200	up	CHARLES@Water	2.7	3.8	1.4	9	45%	55%	600	60	0	16.49	379	22%	205
200	up	HESPELER@Can Amera&YMCA Driveway	5.2	11.2	2.1	25	24%	76%	600	118	30	50.92	222	21%	206
200	dn	KING@KCI &Central Meat	3.6	5.9	1.6	14	38%	62%	658	58	15	25.78	283	21%	207
12	Up	BRIDGE@Dansbury	5.2	11.5	2.2	22	27%	73%	214	364	0	65.15	102	21%	208

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
12	Up	STRASBURG@Forest Glen Plaza	3.6	6.8	1.9	14.4	37%	63%	214	394	0	38.31	152	21%	209
12	Dn	WESTMOUNT@Westcourt/Father David Bauer	5.2	11.1	2.2	25.5	23%	77%	356	76	15	49	92	21%	210
200	dn	CHARLES@Stirling	5.1	12.1	2.4	32	16%	84%	658	88	44	41.59	369	21%	211
23	Up	RIVER@Lorraine	4.8	9.1	1.9	19	29%	71%	222	59	15	39.67	86	21%	212
200	dn	QUEEN@Charles	3.3	5.8	1.8	10	40%	60%	658	76	0	45.51	516	21%	213
53	IB	MAIN@Elgin	4.5	8.7	1.9	19	29%	71%	221	88	29	41.6	124	20%	214
15	ob	VICTORIA@Frederick	5.1	11.7	2.3	26.3	20%	80%	218	76	30	53.38	136	20%	215
23	Up	KING@Benton/Frederick	5.0	10.8	2.2	25	22%	78%	222	61	0	66.3	56	20%	216
12	Up	WESTMOUNT@Blockline	3.1	5.5	1.7	13	37%	63%	214	45	0	34.3	232	20%	217
200	dn	KING@Agnes	4.1	7.8	1.9	17.3	29%	71%	658	46	0	38.72	260	20%	218
12	Dn	STRASBURG@Blockline	3.3	6.3	1.9	12.5	35%	65%	356	76	0	41.4	225	19%	219
52	Up	KING/CORONATION @Concession	4.2	9.4	2.2	19.9	26%	74%	372	30	0	7	99	19%	220
23	Up	FAIRWAY@Lackner	3.6	6.6	1.8	16	30%	70%	222	76	30	25.71	95	19%	221
15	ob	KING@Benton/Frederick	3.6	6.8	1.9	14	31%	69%	218	46	0	51	96	19%	222
200	up	AINSLIE@Main	4.1	8.6	2.1	21	24%	77%	600	90	30	35	285	19%	223
200	dn	UNIVERSITY@Hazel	3.5	6.5	1.9	11.3	34%	66%	658	80	0	48	267	19%	224
23	Down	RIVER@Lorraine	3.3	5.8	1.8	14	30%	70%	219	121	15	21.8	104	18%	225
23	Up	FAIRWAY@Morgan	3.4	5.9	1.7	13	31%	69%	222	94	0	27.4	98	18%	226
1	ob	KRUG@East	3.1	5.5	1.8	12.1	32%	68%	330	61	0	28.94	186	18%	227
12	Up	WESTMOUNT@Greenbrook	4.6	11.3	2.4	23.7	18%	82%	214	60	15	50.7	59	18%	228

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
51	Dn	HESPELER@480&499 Hespeler Road Winners&Shoppers	3.3	6.8	2.0	14	29%	71%	446	120	0	40.67	159	18%	229
29	EB	UNIVERSITY@Phillip	4.5	11.8	2.7	26.8	14%	86%	263	108	0	57.64	41	18%	230
200	dn	NORTHFIELD@Colby /Conestoga	3.3	6.6	2.0	14	29%	71%	658	119	45	28.46	246	18%	231
12	Dn	UNIVERSITY@Seagra m	5.1	15.0	3.0	27	12%	88%	356	76	30	68.44	84	18%	232
9	UP	WEBER@Northfield	5.5	14.9	2.7	17	20%	80%	231	152	15	114.53	55	18%	233
200	up	KING@Union	3.4	6.4	1.9	14.1	28%	72%	600	43	0	57.68	188	18%	234
200	up	HESPELER@Dunbar	3.3	6.6	2.0	14	28%	72%	600	210	45	28.92	238	18%	235
200	dn	CHARLES@Cedar	3.5	7.2	2.0	16	25%	75%	658	122	15	33.32	208	17%	236
201	up	FISCHER HALLMAN@Glasgow	4.4	11.4	2.6	22.7	17%	83%	314	75	15	53.06	59	17%	237
53	IB	FRANKLIN@Jamieson /Holiday Inn	3.0	6.2	2.1	14	28%	72%	221	45	0	47.7	156	17%	238
1	ob	CHARLES@Benton	3.7	8.5	2.3	13.1	27%	73%	330	71	0	69.68	142	17%	239
51	Up	HESPELER@Cambrid ge Centre	3.2	6.6	2.1	16	25%	75%	453	61	15	32.06	548	17%	240
15	ib	KING@Benton/Frederi ck	3.7	9.0	2.5	17.7	21%	79%	214	45	0	85.48	54	17%	241
201	dn	COLUMBIA@Phillip	2.3	4.7	2.1	9	33%	67%	319	103	0	52.15	124	17%	242
201	dn	STRASBURG@Blockli ne	2.5	5.0	2.0	9.2	31%	69%	319	76	0	34.7	217	16%	243
29	EB	UNIVERSITY@WLU Ped	3.6	8.8	2.4	19.8	18%	82%	263	141	0	58.85	58	16%	244
11	IB	STRASBURG@Forest Glen Plaza	2.5	5.0	2.0	11	29%	71%	252	44	0	46.2	192	16%	245

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
23	Down	KING@Benton/Frederick	2.8	6.3	2.2	10.2	29%	71%	219	61	0	44.04	88	16%	246
200	up	HESPELER@Avenue	3.1	6.9	2.2	14	24%	76%	600	107	31	43	260	16%	247
23	Down	WILSON@Kingsway	2.5	5.0	2.0	11	28%	72%	219	62	0	33	125	16%	248
1	ib	KING@Ontario	3.5	10.0	2.8	25	13%	88%	336	90	30	41.76	45	16%	249
9	UP	COLUMBIA@Hazel	4.2	10.9	2.6	17	18%	82%	231	61	15	55.54	145	16%	250
1	ob	RIVER@Holborn	3.3	7.7	2.4	14	23%	77%	330	95	16	59.88	83	16%	251
51	Dn	AINSLIE@Main	3.4	9.2	2.7	24	13%	87%	446	77	0	40.84	70	16%	252
1	ib	CHARLES@Gaukel	2.1	4.2	2.0	9	29%	71%	336	45	0	34.64	141	15%	253
9	UP	UNIVERSITY@WLU Ped	3.3	7.6	2.3	18	18%	82%	231	91	45	28	68	15%	254
201	dn	FISCHER HALLMAN@Columbia	2.4	5.7	2.4	9	29%	71%	319	61	0	64.12	482	15%	255
23	Down	QUEEN@Charles	3.7	9.6	2.6	10.2	24%	76%	219	61	15	54.72	166	15%	256
200	up	FAIRWAY@King	2.6	5.7	2.1	12	25%	75%	600	75	0	45.1	230	15%	257
23	Down	FAIRWAY@Wilson	3.1	7.2	2.3	14	22%	78%	219	75	15	39.6	75	15%	258
12	Dn	FAIRWAY@655 Fairway	3.4	8.4	2.5	18.5	17%	83%	356	91	15	42	103	15%	259
23	Down	OTTAWA@Lackner	2.5	5.7	2.2	9.2	26%	74%	219	46	0	40.99	76	15%	260
12	Dn	WESTMOUNT@Chopin/Brybeck	3.1	7.7	2.5	15.5	19%	81%	356	64	0	46.11	81	15%	261
200	dn	HESPELER@Munch	2.5	5.7	2.3	11	24%	76%	658	61	0	41.96	264	15%	262
23	Down	CHARLES@Benton	3.0	8.0	2.7	11.2	23%	77%	219	74	0	60.9	75	14%	263
23	Up	FREDERICK@Lancaster	3.0	6.8	2.3	14	20%	80%	222	121	0	41.43	97	14%	264
12	Dn	UNIVERSITY@WLU Ped	2.6	5.6	2.1	11.5	23%	77%	356	74	0	28	96	14%	265
11	OB	QUEEN@Charles	2.4	5.9	2.5	10	25%	75%	248	61	0	55.35	230	14%	266
51	Dn	HESPELER@Burger King 580	2.8	6.8	2.4	14	20%	80%	446	92	15	38.94	108	14%	267

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
23	Up	RIVER@Holborn	2.3	5.1	2.2	10	25%	75%	222	61	0	27.46	362	14%	268
15	ob	FREDERICK@River	2.4	5.5	2.3	9.3	25%	75%	218	121	0	38.76	79	14%	269
11	IB	CHARLES@Gaukel	2.6	6.8	2.7	8	25%	75%	252	60	0	67.96	88	14%	270
200	up	AINSLIE@Dickson	2.9	7.2	2.5	18	15%	85%	600	46	15	28.8	132	14%	271
15	ob	QUEEN@Margaret	2.1	4.6	2.2	10	23%	77%	218	60	0	34.92	114	14%	272
51	Up	HESPELER@600&611 Hespeler Road Homesense&Travelodge	2.7	6.8	2.5	11.8	20%	80%	453	57	0	57	112	14%	273
51	Dn	HESPELER@600&611 Hespeler Road Homesense&Travelodge	2.7	6.7	2.5	13	18%	82%	446	119	0	36.3	155	13%	274
200	dn	CHARLES@Francis	3.0	8.3	2.7	12	18%	82%	658	63	0	63.56	219	13%	275
1	ib	KING@Gaukel	2.0	5.3	2.6	8	24%	76%	336	149	0	49.04	97	13%	276
12	Up	DAVENPORT@Old Abbey	2.5	6.5	2.6	12	19%	81%	214	61	0	49.53	61	13%	277
1	ib	KING@Benton/Frederick	2.8	7.7	2.7	11	19%	81%	336	46	0	72.96	83	13%	278
200	up	AINSIE@Parkhill	3.4	9.7	2.9	9	19%	81%	600	74	15	49.64	206	13%	279
53	OB	FRANKLIN@Bishop	3.2	9.0	2.8	11.2	17%	83%	225	137	0	61.48	54	13%	280
51	Up	PINEBUSH@Walmart &Home Depot	3.1	8.6	2.8	10.8	18%	82%	453	74	15	61.02	214	13%	281
9	UP	UNIVERSITY@Hazel	3.0	8.8	2.9	10	19%	81%	231	30	0	80	71	13%	282
15	ob	CHARLES@Benton	2.6	7.3	2.8	7.3	22%	78%	218	78	0	63.85	84	12%	283
1	ib	RIVER@Lorraine	2.6	6.9	2.7	12	17%	83%	336	90	0	41.7	71	12%	284
12	Up	UNIVERSITY@Hazel	2.4	6.4	2.7	8	20%	80%	214	77	0	73.62	57	12%	285
51	Up	PINEBUSH@Conestoga	1.6	3.8	2.3	7	23%	77%	453	72	0	26.52	242	12%	286

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
15	ob	VICTORIA@Edna	1.7	4.4	2.5	8.3	21%	79%	218	61	0	32	123	12%	287
12	Up	UNIVERSITY@Phillip	3.4	10.2	3.0	10.7	13%	87%	214	80	16	48.24	33	11%	288
15	ib	KING@Gaukel	1.6	4.4	2.7	5	22%	78%	214	45	0	41.7	63	11%	289
200	dn	VICTORIA@Charles	2.3	6.3	2.8	9.3	17%	83%	658	43	0	46.28	157	11%	290
200	up	AINSLIE@Simcoe&Market	2.1	5.7	2.7	13	14%	86%	600	72	14	26.36	96	11%	291
12	Up	UNIVERSITY@WLU Ped	2.1	5.5	2.6	10	16%	84%	214	88	44	24.85	47	11%	292
200	dn	KING@Wellington	2.0	5.3	2.7	10	16%	84%	658	86	0	32.2	131	11%	293
23	Up	RIVER@Krug	2.0	5.2	2.6	9.9	16%	84%	222	152	15	49.83	44	11%	294
200	dn	KING@Union	2.3	6.7	3.0	7	18%	82%	658	88	0	56	148	11%	295
12	Up	WESTMOUNT@Highland	1.4	3.5	2.5	6	21%	79%	214	93	0	52.76	67	11%	296
200	up	CHARLES@Borden	1.4	3.4	2.5	7	19%	81%	600	60	0	22	139	10%	297
12	Up	FAIRWAY@655 Fairway	2.3	6.6	2.8	10.7	14%	86%	214	77	31	29	37	10%	298
12	Dn	WESTMOUNT@William	1.5	3.8	2.5	7	19%	81%	356	88	29	20.48	88	10%	299
200	dn	KING@Green	2.1	5.8	2.8	10	14%	86%	658	57	0	43.88	114	10%	300
29	WB	UNIVERSITY@WLU Ped	1.5	3.7	2.5	7	18%	82%	268	46	0	24.2	71	10%	301
13	EB	FISCHER HALLMAN@Columbia	1.3	3.2	2.6	5	20%	80%	235	121	0	26.51	180	10%	302
200	up	KING@Bridgeport	1.1	3.7	3.4	4	21%	80%	600	88	0	53.28	165	10%	303
53	IB	CONCESSION@Christopher	1.5	3.7	2.5	7	17%	83%	221	77	0	24.68	47	10%	304
29	WB	UNIVERSITY@Seagram	4.0	12.5	3.1	4.3	13%	87%	268	119	15	61.55	63	9%	305
12	Dn	BRIDGE@Dansbury	2.9	9.2	3.2	6.5	13%	87%	356	91	0	57.53	83	9%	306

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
201	up	COLUMBIA@Rim Driveway	1.7	4.9	2.8	8	14%	86%	314	42	0	34.4	81	9%	307
23	Down	OTTAWA@Heritage	1.8	5.3	3.0	6.2	16%	84%	219	61	15	29.32	375	9%	308
200	dn	KING@Marshall	1.7	4.8	2.8	8	14%	86%	658	89	44	22.95	121	9%	309
11	IB	KING@Cedar	1.9	5.9	3.1	5	16%	84%	252	91	0	50.66	97	9%	310
15	ib	CHARLES@Gaukel	1.2	3.2	2.6	5	17%	83%	214	60	0	37.55	63	9%	311
23	Down	FREDERICK@Bruce	1.3	4.2	3.3	4	18%	82%	219	75	0	96.87	49	9%	312
200	dn	AINSLIE@Simcoe&Market	1.4	4.0	2.8	6	15%	85%	658	61	15	22.04	140	9%	313
53	IB	DUNDAS@Main	2.0	8.1	4.0	3	16%	84%	221	132	15	64.94	56	8%	314
200	up	KING@Breithaupt	1.5	4.5	3.0	6	14%	86%	600	75	15	26	161	8%	315
12	Up	FAIRWAY@500&589 Fairway	1.3	3.7	2.9	5	15%	85%	214	59	0	35	89	8%	316
201	up	FISCHER HALLMAN@Hwy 7&8 EB Ramp	1.4	4.1	2.9	6.7	13%	87%	314	50	17	30.67	55	8%	317
201	dn	FISCHER HALLMAN@Keatsway	1.5	4.9	3.2	5	14%	86%	319	100	0	46.37	75	8%	318
200	up	UNIVERSITY@Albert	1.6	5.0	3.2	5.1	14%	87%	600	104	0	50.4	88	8%	319
29	EB	KING@Hickory	1.9	6.4	3.4	3.8	14%	86%	263	61	0	63.9	188	8%	320
11	OB	CHARLES@Cedar	1.5	4.7	3.1	5	13%	87%	248	60	0	29.91	87	8%	321
53	OB	FRANKLIN@Sheldon	2.4	8.0	3.4	4.2	12%	88%	225	152	0	58.92	56	8%	322
23	Up	OTTAWA@Heritage	1.6	5.0	3.1	4	14%	86%	222	76	0	37.4	64	8%	323
52	Up	DUNDAS@Beverly	1.6	5.1	3.2	4	14%	86%	372	485	0	34.47	156	8%	324
12	Dn	WESTMOUNT@Laurentian	1.2	3.5	3.0	5.5	13%	87%	356	76	0	26.3	66	8%	325
1	ob	WEBER@Scott	0.8	2.2	2.8	3.1	16%	84%	330	46	0	18.32	141	7%	326
9	UP	NORTHFIELD@Colby/Conestoga	1.4	4.4	3.1	4	13%	87%	231	76	0	35.22	62	7%	327

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201	up	FISCHER HALLMAN@Craigleith&Roxton	1.1	3.2	2.9	4.7	13%	87%	314	45	0	33.4	56	7%	328
201	up	UNIVERSITY@WLU Ped	2.0	6.2	3.1	5.4	11%	89%	314	104	45	25.94	51	7%	329
12	Up	STRASBURG@Bleams	0.9	3.0	3.3	2	16%	84%	214	61	0	41.69	46	7%	330
12	Up	WESTMOUNT@University	0.9	2.7	3.0	3	15%	85%	214	47	0	24.26	51	7%	331
200	dn	CHARLES@Gaukel	1.3	4.4	3.3	3	14%	86%	658	47	0	45	274	7%	332
51	Up	HESPELER@Dunbar	1.0	3.1	3.1	3.8	14%	86%	453	121	0	26.98	157	7%	333
12	Dn	UNIVERSITY@King	1.8	8.8	4.9	2.5	13%	87%	356	120	30	67.92	77	7%	334
29	WB	UNIVERSITY@Hazel	1.2	4.1	3.5	4	13%	87%	268	121	0	34.4	41	7%	335
53	OB	CONCESSION/MAIN @Chalmers	1.4	4.3	3.1	3.6	11%	89%	225	76	0	26.75	122	6%	336
11	OB	CHARLES@Stirling	1.1	3.7	3.3	2	13%	88%	248	74	0	32.7	250	6%	337
201	dn	WESTMOUNT@Blockline	0.6	2.2	3.5	2	13%	87%	319	45	0	29.48	187	6%	338
9	UP	NORTHFIELD@Davenport	0.5	1.5	3.0	2	13%	87%	231	42	0	13.63	44	6%	339
12	Dn	UNIVERSITY@Marsland	1.9	7.0	3.6	0.5	10%	90%	356	121	0	51.88	119	5%	340
201	dn	FISCHER HALLMAN@Craigleith&Roxton	0.9	3.1	3.3	2	11%	89%	319	106	0	30.2	133	5%	341
201	dn	FISCHER HALLMAN@Highland	2.0	8.7	4.4	0.2	10%	90%	319	121	15	67.64	59	5%	342
51	Dn	HESPELER@Cambridge Centre	0.9	3.3	3.6	1.5	11%	89%	446	136	0	43.19	63	5%	343
52	Dn	KING@Lowther	2.3	9.9	4.3	0	9%	91%	372	132	0	155.72	260	5%	344

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201	dn	STRASBURG@Forest Glen Plaza	0.6	2.1	3.4	2	11%	89%	319	107	0	18.81	134	5%	345
15	ib	KING@Ontario	2.1	7.8	3.6	0	8%	92%	214	73	15	38.81	30	5%	346
23	Down	FREDERICK@Otto	1.2	4.4	3.6	0.4	10%	90%	219	60	15	32.6	27	5%	347
23	Up	CHARLES@Ontario	2.2	7.5	3.4	0	8%	92%	222	57	14	32.82	23	5%	348
23	Down	LACKNER@Oldfield/ Zeller	0.7	2.6	3.6	1	11%	89%	219	61	0	24.48	110	5%	349
11	IB	KING@Ontario	2.0	7.4	3.6	0	8%	92%	252	61	15	38	35	5%	350
12	Dn	DAVENPORT@Old Abbey	0.9	3.3	3.6	0.5	10%	90%	356	168	0	23	105	5%	351
200	dn	KING@WLU Ped	0.5	1.9	3.6	1	10%	90%	658	73	0	21.87	296	5%	352
12	Dn	COURTLAND&FAIR WAY@Manitou	0.9	3.3	3.9	0.5	10%	90%	356	45	0	43.8	95	5%	353
200	dn	HESPELER@Avenue	1.1	4.1	3.7	0	10%	90%	658	74	0	38.4	123	5%	354
200	up	KING@Marshall	0.9	3.1	3.6	0.1	10%	90%	600	44	0	24.24	99	4%	355
53	OB	CONCESSION@Christ opher	0.9	3.3	3.7	0	10%	90%	225	61	15	21.66	115	4%	356
12	Dn	UNIVERSITY@Trans Canada Trail	0.5	2.5	5.0	0.5	10%	90%	356	72	0	48.72	78	4%	357
23	Down	RIVER@Holborn	1.2	4.3	3.6	0	9%	91%	219	89	15	27.85	26	4%	358
200	dn	KING@Erb	1.5	5.7	3.9	0	8%	92%	658	75	15	45.55	112	4%	359
23	Up	FREDERICK@Otto	0.8	3.1	3.7	0	9%	91%	222	42	14	25.75	31	4%	360
29	WB	UNIVERSITY@Trans Canada Trail	0.2	0.9	4.4	0.3	10%	90%	268	89	0	30.13	53	4%	361
200	dn	KING@Allen	1.2	4.3	3.7	0	8%	92%	658	61	15	27.67	59	4%	362
200	dn	KING@Central	0.6	2.2	3.6	0	9%	91%	658	89	0	20	79	4%	363
51	Up	HESPELER@480&499 Hespeler Road Winners&Shoppers	1.3	5.5	4.1	0	7%	93%	453	76	15	40.25	46	4%	364
15	ib	CHARLES@Ontario	0.4	1.6	3.9	0	9%	91%	214	47	0	28.48	52	4%	365

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9	UP	UNIVERSITY@Trans Canada Trail	0.5	3.0	6.4	0	9%	91%	231	92	31	32.45	113	4%	366
200	up	UNIVERSITY@Seagram	0.5	2.1	4.5	0	9%	91%	600	46	0	40.01	117	4%	367
12	Dn	STRASBURG@Forest Glen Plaza	0.4	1.6	4.1	0	9%	91%	356	61	0	17	165	4%	368
200	dn	AINSLIE@Main	1.4	5.5	3.9	0	7%	93%	658	45	15	30.08	52	4%	369
29	EB	UNIVERSITY@Seagram	1.7	7.9	4.8	0	6%	94%	263	76	15	60.85	19	3%	370
23	Up	LACKNER@Oldfield/Zeller	0.5	2.0	4.1	0	8%	92%	222	45	0	20	79	3%	371
12	Up	BLEAMS@Century Hill	0.5	2.1	3.8	0	8%	92%	214	74	0	18.68	24	3%	372
12	Dn	BLEAMS@Century Hill	0.4	1.6	3.9	0	8%	92%	356	45	0	16.34	186	3%	373
51	Up	WATER@Dando	0.6	2.5	4.3	0	7%	93%	453	58	14	19.78	50	3%	374
29	WB	UNIVERSITY@Keatsway	0.3	1.4	4.7	0	7%	93%	268	30	0	15.52	25	3%	375
12	Dn	WESTMOUNT@Williamsburg	0.5	2.0	4.1	0	7%	93%	356	59	0	20.56	33	3%	376
23	Down	RIVER@Hickson	0.5	2.3	4.5	0	7%	93%	219	85	14	18.91	19	3%	377
1	ib	CHARLES@Ontario	0.2	1.1	4.3	0	7%	93%	336	47	0	16.76	79	3%	378
200	up	FAIRWAY@Fairview Park Mall	0.3	1.4	4.4	0	7%	93%	600	45	0	17.44	63	3%	379
200	up	KING@William	1.5	7.3	4.8	0	4%	96%	600	106	15	43.52	38	3%	380
15	ob	VICTORIA@Natchez	0.5	2.6	5.0	0	6%	94%	218	61	0	34	35	3%	381
15	ob	VICTORIA@Lackner	0.7	3.3	4.8	0	6%	94%	218	45	0	63.71	187	3%	382
52	Dn	KING@Eagle	0.6	3.1	4.8	0	6%	94%	372	152	0	73.28	355	3%	383
200	up	WATER@Dando	0.6	2.5	4.3	0	6%	94%	600	59	15	37.22	46	3%	384
51	Dn	WATER@Dando	0.3	1.5	4.5	0	7%	93%	446	106	0	16	71	3%	385

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200	up	NORTHFIELD@Colby /Conestoga	0.6	3.0	4.8	0	6%	95%	600	61	15	27.46	264	3%	386
201	dn	COLUMBIA@Albert	0.3	1.5	5.2	0	6%	94%	319	107	0	51.91	80	2%	387
200	dn	CHARLES@Benton	1.0	4.9	4.9	0	4%	96%	658	77	31	32.97	63	2%	388
51	Dn	WATER@Samuelson	0.6	3.2	5.3	0	5%	95%	446	61	15	32.28	38	2%	389
200	up	KING@Agnes	0.6	2.9	4.8	0	5%	95%	600	59	15	27.46	44	2%	390
200	dn	UNIVERSITY@WLU Ped	0.8	3.9	4.9	0	5%	95%	658	108	31	25	61	2%	391
200	dn	AINSLIE@Dickson	0.8	4.1	5.0	0	4%	96%	658	76	15	27	48	2%	392
12	Up	BRIDGE@University	0.3	1.7	4.8	0	5%	95%	214	106	0	20.97	98	2%	393
52	Up	SHANTZ HILL@Preston Parkway	0.7	4.0	6.1	0	4%	96%	372	76	0	39.4	335	2%	394
9	DN	UNIVERSITY@Trans Canada Trail	0.1	0.5	5.5	0	5%	95%	164	42	0	25	35	2%	395
12	Dn	WESTMOUNT@Green brook	0.3	1.4	5.8	0	5%	95%	356	103	0	31.61	38	2%	396
52	Up	KING@Lowther	1.1	8.6	7.8	0	3%	97%	372	104	15	186.16	109	2%	397
200	up	CHARLES@Cedar	0.5	2.7	5.8	0	4%	96%	600	73	15	28.85	37	2%	398
201	dn	FISCHER HALLMAN@Forest Hts Collegiate	0.8	5.1	6.3	0	3%	97%	319	60	15	102.69	56	2%	399
52	Dn	KING@Montrose	0.6	5.6	8.8	0	4%	96%	372	88	15	258.11	90	2%	400
12	Dn	FAIRWAY@Fairview Park Mall	0.5	3.4	6.4	0	4%	96%	356	66	0	52.88	47	2%	401
200	up	CHARLES@Cameron	0.3	1.6	5.2	0	4%	96%	600	46	0	21	50	2%	402
23	Up	RIVER@Hickson	0.2	1.3	5.8	0	5%	95%	222	74	0	14.88	21	2%	403
51	Up	WATER@Samuelson	0.4	2.4	6.2	0	4%	96%	453	76	0	30.92	37	2%	404
200	dn	UNIVERSITY@Trans Canada Trail	0.1	0.4	5.7	0	5%	95%	658	76	0	29.86	284	2%	405
201	up	FISCHER HALLMAN@Keatswa y	0.4	2.6	5.9	0	4%	96%	314	76	15	25.79	15	2%	406

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200	dn	KING@Montgomery	0.2	1.1	6.1	0	4%	96%	658	344	0	19.55	64	2%	407
52	Dn	DUNDAS@Easton	0.3	1.9	5.9	0	3%	97%	372	79	16	31.4	325	2%	408
52	Dn	KING@Tu Lane	0.4	3.4	8.0	0	3%	97%	372	470	15	61.65	168	2%	409
200	dn	KING@Pine	0.1	1.1	7.9	0	4%	96%	658	46	0	26.93	46	1%	410
200	dn	WATER@Samuelson	0.4	2.7	6.1	0	3%	97%	658	88	15	25.58	27	1%	411
200	up	KING@Victoria	0.7	4.9	7.4	0	3%	98%	600	72	0	61.67	29	1%	412
12	Up	WESTMOUNT@Gage	0.3	2.0	5.9	0	3%	97%	214	59	15	23.51	9	1%	413
9	DN	WEBER@Albert	0.1	0.8	6.0	0	4%	96%	164	61	0	16	64	1%	414
9	DN	UNIVERSITY@WLU Ped	0.4	2.4	6.5	0	3%	97%	164	43	0	27.78	17	1%	415
52	Dn	MAIN@Wellington	0.3	2.4	7.2	0	3%	97%	372	72	29	36.6	193	1%	416
200	dn	WATER@Dando	0.2	1.3	6.8	0	3%	97%	658	75	15	15.72	36	1%	417
12	Dn	WESTMOUNT@Gage	0.2	1.4	6.1	0	3%	97%	356	60	0	23.94	22	1%	418
201	up	FISCHER HALLMAN@Highland Hills Mall	0.3	2.3	7.1	0	3%	97%	314	77	15	24.95	18	1%	419
23	Down	RIVER@Krug	0.2	1.1	7.2	0	3%	97%	219	75	0	16.7	17	1%	420
51	Dn	HESPELER@Dunbar	0.1	1.0	7.8	0	3%	97%	446	76	15	70.18	655	1%	421
200	up	WATER@Samuelson	0.2	1.5	7.0	0	3%	97%	600	75	0	31	25	1%	422
52	Up	FAIRWAY@King	0.3	3.0	8.7	0	2%	98%	372	76	0	63.25	167	1%	423
200	dn	CHARLES@Cameron	0.3	2.6	7.6	0	2%	98%	658	45	0	42.8	50	1%	424
52	Dn	KING@Westminster	0.3	2.0	7.7	0	2%	98%	372	44	0	253.04	165	1%	425
200	up	KING@KCI &Central Meat	0.3	2.2	7.6	0	2%	98%	600	45	0	35.58	35	1%	426
1	ob	RIVER@Hickson	0.2	1.2	6.6	0	2%	98%	330	45	0	19	16	1%	427
12	Dn	WESTMOUNT@Dietz	0.2	1.4	7.3	0	2%	98%	356	90	0	24.67	12	1%	428
51	Up	HIGHWAY 24@Hwy 401 WB Ramp	0.3	2.8	8.2	0	2%	98%	453	76	0	98.2	588	1%	429
1	ib	RIVER@Hickson	0.2	1.2	7.5	0	2%	98%	336	45	0	22.58	12	1%	430
52	Dn	KING/CORONATION @Concession	0.2	2.4	9.9	0	2%	98%	372	484	0	95.14	75	1%	431

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
52	Dn	KING@Dolph	0.5	6.1	12.5	0	1%	99%	372	73	0	194.88	119	1%	432
200	dn	KING@Breithaupt	0.2	1.9	9.5	0	2%	98%	658	62	0	156.71	17	1%	433
200	dn	CHARLES@Borden	0.2	1.6	8.5	0	2%	98%	658	60	0	28.1	17	1%	434
52	Up	SPORTSWORLD@Gateway	0.1	0.8	8.1	0	2%	98%	372	167	15	74.24	120	1%	435
12	Dn	WESTMOUNT@Forest Hill Public School	0.1	1.0	9.2	0	2%	98%	356	103	0	27.94	20	1%	436
12	Up	UNIVERSITY@King	0.3	3.3	10.4	0	1%	99%	214	58	15	64.46	21	1%	437
52	Up	KING@Westminster	0.1	1.2	8.7	0	1%	99%	372	73	0	27.73	100	1%	438
52	Dn	KING@Bishop	0.3	4.6	13.4	0	1%	99%	372	45	0	187.9	135	1%	439
200	up	CHARLES@Francis	0.1	1.0	9.9	0	1%	99%	600	59	0	20.73	16	1%	440
200	up	VICTORIA@Charles	0.1	1.5	12.3	0	1%	99%	600	63	16	34.36	20	1%	441
9	UP	NORTHFIELD@Kraus	0.0	0.5	10.0	0	1%	99%	231	34	0	44.01	6	1%	442
201	up	FISCHER HALLMAN@Thorndale	0.1	1.1	11.2	0	1%	99%	314	32	0	32.85	8	0%	443
200	up	KING@Rockway Seniors Centre	0.0	0.6	12.0	0	1%	99%	600	75	0	19.76	12	0%	444
200	up	KING@1668 1680 King	0.0	0.3	11.9	0	1%	99%	600	180	0	21.97	23	0%	445
12	Up	WESTMOUNT@Forest Hill Public School	0.0	0.2	10.5	0	1%	99%	214	88	0	22.82	12	0%	446
52	Up	KING@Montrose	0.0	0.5	11.8	0	1%	99%	372	89	0	16.64	114	0%	447
52	Up	KING@Eagle	0.0	0.3	11.2	0	1%	99%	372	106	0	7.88	30	0%	448
52	Up	KING@Waterloo	0.0	0.3	12.5	0	1%	99%	372	62	0	18.16	171	0%	449
200	dn	CONESTOGA@Dunbar&Lena	0.0	0.7	16.3	0	1%	99%	658	45	0	48.95	17	0%	450
51	Up	HESPELER@Burger King 580	0.1	1.0	13.8	0	1%	99%	453	44	0	54.8	10	0%	451
52	Up	FAIRWAY@Hwy 8 EB Ramp	0.1	1.5	17.0	0	1%	99%	372	45	0	62.3	220	0%	452

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
52	Dn	WILSON@Kingsway	0.0	0.5	16.4	0	1%	99%	372	74	0	75.96	5	0%	453
52	Dn	HESPELER/WATER@ Coronation/Dundas	0.0	0.3	16.8	0	1%	99%	372	61	0	66.25	28	0%	454
52	Up	FOUNTAIN@Shantz Hill	0.0	0.2	14.4	0	1%	99%	372	46	0	40.43	20	0%	455
12	Up	WESTMOUNT@Chopi n/Brybeck	0.0	0.3	14.6	0	0%	100%	214	45	0	19.64	6	0%	456
9	UP	DAVENPORT@Old Abbey	0.0	0.5	15.2	0	0%	100%	231	75	0	13.79	43	0%	457
53	IB	FRANKLIN@Main	0.0	0.2	14.9	0	0%	100%	221	61	0	8	12	0%	458
52	Dn	KING@Deer Ridge	0.1	1.2	19.3	0	0%	100%	372	61	15	38.74	306	0%	459
200	up	KING@Central	0.0	0.2	20.8	0	0%	100%	600	93	0	21.49	7	0%	460
52	Up	DUNDAS@Hopeton	0.0	0.7	19.3	0	0%	100%	372	61	0	28.82	108	0%	461
52	Dn	BEVERLY@Kerr	0.0	0.6	19.3	0	0%	100%	372	91	0	124.16	305	0%	462
201	up	FISCHER HALLMAN@Forest Hts Collegiate	0.0	0.1	17.7	0	0%	100%	314	50	0	16.91	6	0%	463
52	Dn	DUNDAS@Hopeton	0.0	0.2	19.3	0	0%	100%	372	215	0	30.85	67	0%	464
52	Up	WELLINGTON@Dick son	0.0	0.2	19.3	0	0%	100%	372	71	14	6.91	85	0%	465
52	Up	KING@River	0.0	0.1	19.3	0	0%	100%	372	227	0	24.56	159	0%	466
10	up	MANITOU@Wabanaki	0.0	0.0	N/A	0	0%	100%	217	45	0	1	30	0%	467
52	Up	HESPELER/WATER@ Coronation/Dundas	0.0	0.0	N/A[1]	0	0%	100%	372	62	0	1	57	0%	468
12	Dn	FAIRWAY@Wilson	N/A[2]	N/A	N/A	N/A	N/A	N/A	356	N/A	N/A	N/A	0	N/A	N/A
12	Up	FAIRWAY@Wilson	N/A	N/A	N/A	N/A	N/A	N/A	214	N/A	N/A	N/A	2	N/A	N/A
12	Up	WESTMOUNT@Dietz	N/A	N/A	N/A	N/A	N/A	N/A	214	N/A	N/A	N/A	2	N/A	N/A

[1] This "N/A" represents that COV is able to be calculated as a result of zero mean.
[2] This "N/A" represents that sample size is not enough for application of proposed methodology.

Route	Direction(given by GRT traffic signal layer information)	Intersection name (given by GRT traffic signal layer information)	Mean delay(s)	Std	COV	90% Percentile Delay(s)	Proportion of trip with delay	Proportion of trip without delay	Number of total service trip	Queue length X_{P2}(m)	Saturation degree Indicator X_{P1}(m)	Maxdelay d_{max}(s)	Sample size	Index	Rank
200	dn	KING@1668 1680 King	N/A	N/A	N/A	N/A	N/A	N/A	658	N/A	N/A	N/A	2	N/A	N/A
200	up	KING@Green	N/A	N/A	N/A	N/A	N/A	N/A	600	N/A	N/A	N/A	2	N/A	N/A
29	WB	UNIVERSITY@King	N/A	N/A	N/A	N/A	N/A	N/A	268	N/A	N/A	N/A	2	N/A	N/A
52	Dn	FAIRWAY@Fairview Park Mall	N/A	N/A	N/A	N/A	N/A	N/A	372	N/A	N/A	N/A	2	N/A	N/A
52	Up	MAIN@Wellington	N/A	N/A	N/A	N/A	N/A	N/A	372	N/A	N/A	N/A	2	N/A	N/A
53	OB	MAIN@South Cambridge Mall	N/A	N/A	N/A	N/A	N/A	N/A	225	N/A	N/A	N/A	2	N/A	N/A
52	Dn	FAIRWAY@Wilson	N/A	N/A	N/A	N/A	N/A	N/A	372	N/A	N/A	N/A	4	N/A	N/A
15	ib	LACKNER@Keewatin	N/A	N/A	N/A	N/A	N/A	N/A	214	N/A	N/A	N/A	4	N/A	N/A
200	up	KING@Allen	N/A	N/A	N/A	N/A	N/A	N/A	600	N/A	N/A	N/A	4	N/A	N/A